2005

Response of Vegetation and Endangered Waterbirds to Habitat Management Techniques at Kealia Pond National Wildlife Refuge

James Andrew Rader
South Dakota State University

Response of Vegetation and Endangered Waterbirds to Habitat Management Techniques at Kealia Pond National Wildlife Refuge

By

James Andrew Rader

A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Wildlife

2005

Response of Vegetation and Endangered Waterbirds to Habitat Management Techniques at Kealia Pond National Wildlife Refuge

This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science degree and is accepted for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Dr. Leigh H. Fredrickson
Thesis Advisor Date

Dr. Charles Scalet
Department Head Date

Acknowledgments

I would like to thank Dr. Leigh Fredrickson for the opportunities and direction he has provided me. I appreciate his encouragement to pursue my interests in wetland and waterfowl management. I also appreciate the prospect to examine wetlands and landscapes throughout the United States. I want to thank Dr. Daniel Hubbard and Dr. Steve Chipps for being on my committee and Dr. Marty Berg of Loyola University of Chicago for helping with statistics. I also appreciate the help of Matt Coplan in generating the drawings of my sampling apparatuses.

Thank you to the U.S. Fish and Wildlife Service and Ducks Unlimited for the funding to study the endangered waterbirds of Hawai'i. To the staff of Kealia Pond National Wildlife Refuge, thank you for the assistance in implementation of this project and the friendships that made Mau'i feel like a home away from home. I enjoyed the discussion about management of Kealia Pond with Glynnis Nakai and Mike Nishimoto. I am indebted to Pat Savino who spent endless hours securing housing for me and my technicians. I also appreciate the time and efforts of Nichole Davis and Calvin Willis during my time on the refuge.

Finally, I would like to express my gratitude to my family and friends for the support and encouragement throughout my education and time away pursuing my interests in waterfowl. I lastly want to thank Jennifer Koshorek, for all her support and help in developing my ideas. I will forever be indebted for all her love, suggestions, time, and patience.

Abstract

Response of Vegetation and Endangered Waterbirds to Habitat Management Techniques at Kealia Pond National Wildlife Refuge

James Andrew Rader

2005

Habitat selection, reproductive effort, and habitat utilization of Hawai'ian stilts (*Himantopus mexicanus knudseni*) and Hawai'ian coots (*Fulica alai*) was studied on Kealia Pond National Wildlife Refuge in Mau'i, Hawai'i. Nesting behavior was confirmed following management treatments on the northern shore of Kealia Pond. Nests were dispersed or randomly spaced within vegetation patches or newly created mudflat habitat. Pickleweed and makai were the dominant vegetation surrounding the nest setting and utilized for nest substrate by Hawai'ian stilts and Hawai'ian coots respectively.

Mechanical control treatments were implemented through monotypic stands of pickleweed to increase interspersion of open water and promote native vegetation. Changes in habitat conditions increased nesting for both species of endangered Hawai'ian waterbirds. In 2003, habitat conditions on the northern shore prevented nesting. In 2004, 32 stilt nests and 69 coot nests were found compared to no nests in previous years. Mass loss of 123 stilt and 320 coot eggs were monitored during incubation in 2004. A constant rate of mean mass loss accounted for approximately 14.32% and 9.07% of the mean fresh egg mass loss for stilts and coots respectively. The Mayfield nest success in 2004 for stilts was 0.38 and 0.36 for coots.

Habitat utilization of both endangered waterbirds was examined in 2003 and 2004. Hawai'ian waterbirds highly selected newly created habitats over other habitats of similar water depths. Hawai'ian coot utilization of water depths were dominated in depths that required swimming. Hawai'ian stilts were most often observed in water depths in relation to their bodies ranging from foot to body. Hawai'ian coots were predominately observed feeding and in locomotion while stilts were predominately observed feeding in treated habitats.

The abundance of habitat utilization through the course of this study allowed for conjecture on management strategies and demographics of breeding populations. Endangered Hawai'ian waterbirds depend on early successional habitat for nesting and foraging. Vegetation resulting from seasonally-flooded management strategies may increase nesting activities by these birds by increasing the proportion of native vegetation on treated sites. Further research is needed to understand vegetation characteristics resulting from habitat manipulations and the life history strategies employed by these birds during the breeding season.

Table of Contents

List of Tables

Page

Chapter 5

Chapter 6

List of Figures

Page

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6

Introduction:

Mau'i historically supported a diverse array of waterbirds in wetland and forest habitats. However, during the past 2000 years of human presence, all of Hawai'i's endemic rails, flightless geese, and one ibis species have become extinct (Olson and James 1991, USFWS 1999a). This massive extinction is attributed to the impacts of humans and invasive plants and animals introduced to Hawai'i (USFWS 1999a). Although Mau'i County only comprises 18% of the area in Hawai'i, it's inhabited by 11% of the state's population according to the 2000 census (U.S. Census Bureau 2003). The expansion of highways and urban development in flood control areas has compromised wetland habitats. Most commonly are those occurring at low elevations.

Historic changes in waterbird numbers were attributed to hunting, but presently the primary cause of population decline and changes in distribution is the loss and modification of wetland habitat. A significant amount of Hawai'i's wetlands have been filled or otherwise modified due to urbanization and development for recreation. Hawai'i contains approximately 44,320 ha (110,800 ac) of wetlands and deep water habitats, of which 81% are classified as palustrine scrub-shrub forest habitats (not utilized by Hawai'i's four endangered waterbirds) (USFWS 1999a). The United States Fish and Wildlife Service (USFWS) estimated that 8990 ha (22,475 ac) of wetlands existed within the coastal plains of Hawai'i circa 1780 (USFWS 1990). In 1990, Hawai'i's wetland area encompassed 6190 ha (15,474 ac), a 31% loss from the original estimate (Dahl 1990).

With the reduction in functional wetland habitat, wetland dependent populations have decreased (Brown and Dinsmore 1986). Efforts to protect and restore endemic waterbird populations in Hawai'i began with the establishment of Kanaha Pond on Mau'i in 1952; the first state wetland sanctuary. This important wetland is now within a highly urbanized environment where management potential is limited. As effective habitat enhancement programs became more important, the USFWS established several waterbird refuges in the 1970's and encouraged future research on Hawai'ian waterbirds (Chang 1990).

Limited studies have investigated the responses of Hawai'ian waterbirds to change in habitat resulting from vegetation and water manipulations. Studies conducted through the University of Missouri for the USFWS from 1985 - 1987 contributed to an understanding of how type, availability, dispersion, and quality of wetlands influence Hawai'ian waterbird concentrations and behaviors (Chang 1990).

The goal of this study was to provide baseline data on the ecology of Hawai'ian coots and stilts and assess the responses of these waterbirds to vegetation manipulations in a managed seasonal wetland. The study assessed habitat characteristics for the breeding of Hawai'ian coots and stilts on Kealia Pond National Wildlife Refuge in Mau'i, Hawai'i, during 2003 and 2004. The first objective was to identify habitat characteristics that were selected by breeding Hawai'ian coots and stilts. The second objective was to monitor Hawai'ian coot, Hawai'ian stilt, and vegetation responses to wetland vegetation manipulations. This information will aid the staff at Kealia Pond National Wildlife Refuge and other Hawai'ian wetland managers in making management decisions based upon the life histories of endangered wetland dependent waterbird species in Hawai'i.

Literature Review:

Waterbird Conservation

Waterbird conservation depends on the preservation of key areas of critically important habitat throughout a birds range in combination with a sound understanding of species biology (Morrison 1991). With continuous loss, reduction in habitat quality, and concurrent decline in waterbird populations, contemporary public and private wetland managers must make a multitude of decisions for multiple species, even though little information may be available on life-history strategies and habitat requirements (Helmers 1993). Reversing the decline of wetland wildlife populations and improving conditions for a greater diversity of wildlife requires implementing programs based on ecologic principles (Fredrickson and Laubhan 1994a). Foremost among these is the recognition that the resources necessary to successfully complete annual cycle events, as well as the strategies and geographic area used to acquire such resources, vary by species (Fredrickson and Reid 1986, 1988, Fredrickson and Laubhan 1994b) Effective management requires a knowledge of migration chronology, habitat use, food requirements, and foraging models for different guilds within a specific geographic region (Fredrickson and Reid 1986). Wetland managers should consider temporal separation in peak abundances between guilds and spatial separation in relation to water depth, vegetation distribution, and foraging patterns (Fredrickson and Reid 1986, Helmers 1993).

Hawai'ian Wetlands

Hawai'ian wetlands have limited plant diversity and waterbird richness compared to continental wetlands. Introduction of exotic wetland plants and alterations in wetland hydrologic regimes have altered the abundance, structure, and species composition of Hawai'ian wetland vegetation. Approximately 55% of the plants in Hawai'ian wetlands are exotic (Stemmermann 1981). The presence of the exotic plants and animals, Hawai'i's moderate climate and year-long growing season, and modifications in abiotic conditions tend to stabilize conditions in Hawai'ian wetland systems. Wetlands dominated by invasive monotypic stands of vegetation often are unproductive sites for aquatic invertebrates, plants, and endangered waterbirds (USFWS 1998). Plant species such as California grass (*Brachiaria mutica*), Cattail (*Typha angustata*), Pickleweed (*Batis maritima*), Indian marsh fleabane (*Pluchea indica*), water hyacinth (*Eichornia crassipes*), California bulrush (*Scirpus californicus*), and American mangrove (*Rhizopora mangle*) cause serious problems in many Hawai'ian wetland systems by reducing the interspersion of open water and vegetation (Stemmermann 1981). Although little information is available regarding the native plant species composition of wetlands, paleobotany suggests (Cummings 1993) many plants that characterized the wetland flora in the Hanalei Valley were probably members of the cyperus family [i.e., nutsedges (*Cyperus spp.*), spike rushes (*Eleocharis spp.*), bulrushes (*Schoenplexus spp.*), bald rushes (*Fimbristylis spp.*)] (USFWS 1998). The cyperus family has many naturalized representatives throughout the Hawai'ian NWR wetland system.

Seasonally-Managed Wetlands

Seasonally-managed wetlands have been identified as one important option to provide high quality habitat for endangered Hawai'ian waterbirds (Griffin 1994). Such sites provide diverse habitats that continually support a multitude of wildlife species, including waterfowl (Fredrickson and Taylor 1982). National Wildlife Refuges throughout the United States have regularly implemented seasonally-flooded management strategies to effectively control invasive vegetation, promote germination and growth of desirable plants as well as to produce invertebrates for waterbirds. Wetlands and associated plant communities, including native and naturalized species, should be managed to mimic natural systems. However, within many highly modified systems there is little potential to provide suitable hydrologic conditions for waterbirds therefore; intensive management becomes important to produce food resources and habitat conditions appropriate for target species.

Intensive management may include drawdown/flooding, soil disturbance with tillage equipment, herbicides, and fire, when appropriate, to provide the structure and foods required by endangered birds for nesting, foraging, loafing, brooding, and cover (USFWS 1998). Different wildlife species have different vegetation structural needs. Shorebirds require open water, with less than 50 percent dense emergent vegetation (Helmers 1993) whereas rails require dense cover with few openings. Open conditions allow shorebirds to forage in open shallow water and mudflats as drawdowns occur (Rundle and Fredrickson 1981, Hands *et al.* 1991, Helmers 1991).

Soil and Vegetation Disturbance

The degree of disturbance determines whether wetlands are dominated by annuals or perennials. Annuals dominate when disturbance is frequent and perennials dominate when disturbance is reduced or lacking (Fredrickson and Taylor 1982). Perennials are difficult to control and many species provide little to no benefit for foraging waterbirds. In contrast perennials are critical to provide nesting habitat for some waterbird groups such as rails, over-water nesting Anatids, marsh nesting passerines, and some herons. Manipulation of vegetation may be desirable to set back succession, to reduce monocultures of robust plants, to diversify monotypic plant communities with undesirable characteristics, to reduce woody invasion, and to modify vegetation structure (Fredrickson and Reid 2001). The inability to control water levels in some wetland systems, compromises the potential for soil and water disturbance. Disturbances tend to disrupt monocultures of robust plants and set back plant succession to a composition dominated by annuals. Disking and mowing of plants in late summer initiates the decomposition process. The soil disturbance and damp conditions result in germination and production of high quality green browse such as blunt spike rush (*Eleocharis obtusa*) (Kelley 1986). Annuals, resulting from soil disturbances on Hawai'ian refuges, include wetland plants such as arrowhead (*Sagittaria sagittaefolia*), barnyard grass (*Echinochloa crusgalli*), wigeon grass (*Ruppia maritima*), and spike rush (*Eleocharis spp.*) (USFWS 1999b) that provide benefits to foraging endangered species (i.e., Hawai'ian coot, Koloa, and Hawai'ian moorhen) either directly or indirectly. Mowing of a 2.0 ha monotypic stand of pickleweed of over 90% vegetative cover resulted in a 50:50 ratio of vegetation to open water in impoundment A of the Kii Unit at James Campbell NWR (Chang 1990). Hawai'ian waterbirds responded dramatically to this increased interspersion. Following similar treatments at the Honolui'lui' Unit of Pearl Harbor NWR, numbers of Hawai'ian Coot nests increased from a couple per year before the restoration to over 88 nests the following two treatment years (Chang 1990). After soil treatments in the 28.4 ha (70 ac) Kii Unit during 1985, 657 representatives from all endangered waterbirds were present from 1985-1988. Hatching success of waterbird nests ranged from 47% to 70% during this period (Chang 1990).

Waterbird Management

Three major strategies are used for waterbird management: 1) the protection of important breeding, migrating and wintering habitats (Senner and Howe 1984, Helmers 1993), 2) the reduction of disturbance and 3) an increase in the accessibility of appropriate habitats in managed wetlands (Helmers 1993). These techniques provide resources for waterbirds in coastal or interior wetlands, and can easily be incorporated into other management strategies (Helmers, 1993).

The Hawai'ian Waterbirds Recovery Plan (Walker *et al.* 1977), General Actions-Habitat Oriented section, indicates that a major objective is to protect and stabilize primary habitats for endangered waterbirds through the following: "Intensification of management and development of designated sanctuaries and refuges to maximize the value of the habitat to the species." It is therefore important to monitor populations within managed sanctuaries to determine nest success and habitat association.

Measurement of nesting success and associated vegetation allows identification of habitat features, greater insight into habitat requirements and species coexistence than traditional matrices such as presence or abundance (Martin 1986, 1988, 1992).

Hawai'ian Stilt Ecology

Introduction

The Hawai'ian stilt (*Himantopus mexicanus knudseni*) or Ae'o is one of two members of the Family Recurvirostrade that are listed as endangered (Coleman 1981). The Hawai'ian stilt is clearly allied with the black-necked stilt of the mainland and is considered one of three distinct subspecies (American Ornithologists' Union 1983, Robinson *et al.* 1999). Hawai'ian subspecies occur on all major islands from Ni'ihau eastward to Hawai'i except for Lāna'i and Kaho'olawe of the Hawai'ian Archipelago (Pratt 1987, American Ornithologists' Union 1983, Robinson *et al.* 1999). Stilts have occurred at least once on Lāna'i (Engilis and Pratt 1993), and occurrence on Hawai'i were thought to be due to relative recent recolonization after several decades of absence (Munro 1944, Paton *et al.* 1985, Banko 1988, Robinson *et al.* 1999)

Description

Hawai'ian stilts are large, long-legged shorebirds. They measure from 35 to 39 cm long including a 5.7 to 7.0 cm bill, weigh 199 to 206 g, and the sexes are similar in size (Coleman 1981, Robinson *et al.* 1999). The Hawai'ian stilt is a slender wading bird, black above, white below and with distinctive pink legs. Patterns of black and white on crown and neck are similar in overall appearance to nominate *H. mexicanus* but adults of

H. knudseni show greater extent of black on forehead and cheeks (Robinson *et al.* 1999). The sexes can be recognized by subtle differences in appearance and vocalizations. The male has black feathers and a high, clearer tone quality in contrast to the female's brownish back feathers and lower pitched voice (Coleman 1981).

Population Status

Because of hunting and habitat loss, Hawai'ian stilts declined to approximately 200 birds in 1944 (Munro 1960, Robinson *et al.* 1999). This population however may have been an underestimate, as other estimates from the late 1940's place the population at approximately 1000 birds (Schwartz and Schwartz 1949, USFWS 1999b). The Hawai'ian stilt was a popular game bird, and hunting contributed to local population declines until waterbird hunting was prohibited in 1939 (Schwartz and Schwartz 1949, USFWS 1999b).

The Hawai'ian stilt was added to the Federal endangered species list in 1970 (USFWS 1970) and assigned a priority number of 9 on a scale of 1 to 18 (1C being highest priority), using a system derived by the USFWS (USFWS 1983, USFWS 1999a). Long-term census data indicates that the statewide populations have remained stable or have increased slightly for the last 30 years (Reed and Oring 1993). From 1983 to 1996, statewide surveys documented 1500 or more stilts in the state (State Dept. of Land and Natural Resources Water Bird Surveys 1983 to 1996). Recent estimates place the population at approximately 1200 to 1600 birds (Griffin *et al.* 1990, Engilis and Pratt 1993) with a high year to year variability in the number of stilts observed (Fig. 2-1) (USFWS 1999a).

Locomotion

Stilt movements vary dependent on distance of travel. For short distances, stilts normally walk or wade rather than flying. They generally shake their feet to remove mud when they exit from water (Hamilton 1975, Coleman 1981, Robinson *et al.* 1999). When in flight, head and legs are extended. After flight, stilts prefer to alight on land and walk into the water (Robinson *et al.* 1999). Although black-necked stilts can swim and dive if necessary (Bent 1927, Robinson *et al.* 1999), they do so awkwardly and avoid these behaviors unless under duress (Mortimer 1890, Robinson *et al.* 1999)

Habitat

Hawai'ian stilts utilize islets, islands, edges of shallow ponds, mudflats where water is fresh to saline up to 116 ppt (Coleman 1981, Robinson *et al.* 1999) and ancient fish ponds constructed by Hawai'ians (Morin 1994). Stilts prefer to nest on freshly exposed mudflats, interspersed with low growing vegetation. Nesting also occurs on islands in fresh or brackish ponds (Shallenberger 1977). Higher nesting densities are found on large mudflat expanses interspersed with vegetation (USFWS 1983, USFWS 1999a).

Stilts exploit a variety of habitats but are limited by water depth and vegetation cover. Stilts require early successional wetlands with water depth less than 24 cm (9 in), annual vegetation, or exposed tidal flats (USFWS 1999a). Stilts forage and nest in different wetland sites. Feeding habitat consists of shallow water that is fresh, brackish, or saline. While wading, stilts tend to feed in water at any depth up to the height of the breast (Telfer 1973). Loafing areas are generally open mudflats, *Batis* flats, or open pasture lands where visibility is good and predator pressure is low (USFWS 1999a).

Nesting Association with Water and Other Nests

Hawai'ian stilt nests are often on small, low-relief islands or in vegetated clumps (Telfer 1973) within bodies of fresh, brackish, or salt water. Coleman (1981) reported that 80 percent of all nests were located on islands ranging from 20 cm to 20 m in diameter. Although nests are often in the open, some nests were at sites where mean vegetative cover was 56 percent (James 1995). In O'ahu, 319 nests were distributed from 1.49-5.61 m away from water (Coleman 1981).

Hawai'ian stilts are generally regarded as semicolonal nesters (Coleman 1981). Hamilton (1975) arbitrarily delineated the "colony" as those nests loosely associated on the same dike. Coleman (1981) delineated the "colony" as a cluster of nests within a particular pond or habitat. Overall average distances between active nests within a "colony" ranged from 21 m to 70 m, but the nearest active nests were only 2 m apart (Coleman 1981).

Nest Characteristics

Hawai'ian stilt nests are scrapes lined with a variety of construction materials (Robinson *et al* 1999). Stems collected from the surrounding area are placed over each other in a spoke-like fashion. Degree of lining varies from none to fully lined with woven grasses. Outer nest diameters are 14-19 cm with a depth of 3.8-5.1 cm (Coleman 1981). The mean nest height above water was 1.2 cm (Coleman 1981). Nests may be built up during changing water levels, yet many nests are thought to be vulnerable to flooding and often are lost before construction to increase nest height occurs.

Chronology

The peak breeding season for Hawai'ian stilts is mid February through late August. Peak nesting may vary among years (Coleman 1981). The variability in nest chronology may be a combination of climate and individual fitness of breeding individuals, but is more likely associated with habitat conditions.

Hawai'ian stilt eggs are pyriform and smooth shelled with an initial base color of dull mint green, which fades to tan 1 day after laying (Coleman 1981). A typical clutch is 4 eggs laid at a rate of 1 egg/day. Supernormal/supernumerary clutches (clutches ≥ 6 eggs) occur occasionally when 2 females lay in the same nest cup (Coleman 1981). Dropped eggs, eggs laid on the ground without evidence of scraping, have also been noted (Coleman 1981).

Incubation begins as soon as the first egg is laid, but may depend on local ambient temperatures. Male and female share incubation duties and usually alternate throughout the day (Grant 1982, Robinson *et al.*1999). Chicks hatch asynchronously over a 24 to 48 hour period after 23-26 days of incubation (Berger 1967, Ueoka *et al.* 1976, Coleman 1981, Robinson *et al.*1999). Young chicks are precocial and downy. Once dry the young are able to leave the nest within 1-2 hours, but walk awkwardly for the first day. Chicks remain with the parents for several months (Coleman 1981).

Causes of Mortality

A variety of predators influence the success of Hawai'ian stilts. Mammalian predators have had an impact on all waterbird populations (Griffin *et al.*1990, USFWS 1999a). Mongooses (*Herpestes auropunctatus*) were first introduced to the Big Island in 1883 and subsequently to Mau'i, Moloka'i, and O'ahu (USFWS 1999a). Feral cats (*Felis catus*) became established in Hawai'i shortly after European contact and were common in O'ahu forests as early as 1892 (Tomich 1969, USFWS 1999a). Other introduced species, such as the cattle egret (*Bulbulcus ibis*), bullfrog (*Rana catesbeiana*), and barn owl (*Tyto alba*), also have a negative impact on the Hawai'ian stilt (USFWS 1999a).

Weather also impacts nest success. Sudden rises in water level may flood nests established on mudflats. Egg loss is primarily due to flooding (Sordahl 1996, Ohashi and Telfer 1977, Dougherty *et al.* 1978, Woodside 1979, Coleman 1981, Robinson *et al.* 1999). Strong trade winds initiating wave action also pose a threat to nests. Avian diseases, such as botulism, also are a recurrent problem at Hawai'ian NWRs.

Hawai'ian Coot Ecology

Introduction

The Hawai'ian coot (*Fulica alai*) or 'Alae ke'oke'o is endemic to the Hawai'ian Islands. The AOU recognized the Hawai'ian coot as a distinct species following Pratt (1987), in the 39th supplement of the <u>Checklist of North American Birds</u> (American Ornithologists' Union 1993). The Hawai'ian coot breeds on Ni'ihau, Kaua'i, Mau'i, and Hawai'i and visits Lāna'i and the Northwestern Hawai'ian Islands west to Kure Atoll (Pratt and Brisbin 2002). The Hawai'ian coot was regarded as absent from Lāna'i prior to 1990's when coots appeared in numbers on water treatment ponds in Lāna'i City and Manele Flats (Engilis and Pratt 1993, Pyle 1994). Undoubtedly, Hawai'ian coots were more widely distributed in prehistoric times when taro cultivation was more extensive and coastal fishponds were more numerous (Morin 1994, Pratt and Brisbin 2002).

Description

The Hawai'ian coot is similar in body size to the closely related mainland species, but the most obvious differences are in size, shape, and color of the bill and frontal shield. Hawai'ian coots have a large bulbous, white frontal shield distinctly larger than that of the American coot (Shallenberger 1977) and in adults the shield extends far enough on the crown to be visible from behind (Pratt and Brisbin 2002). A few individuals have dark-red shields and are denoted by the Hawai'ian name *Alae Awi*. Coots have dark, slate-gray plumage and white undertail feathers. Leg colors consist of pale light gray to dull olive gray and are rather long. Males and females are similar in color.

Population Status

Coots have always been most numerous on O'ahu, Mau'i, and Kaua'i (Shallenberger 1977). Censuses from the late 1950's to the late 1960's indicated a population of fewer than 1000, contributing to the listing of the Hawai'ian coot as federally endangered. The Hawai'ian Coot was added to the Federal endangered species list in 1970 (USFWS 1970) and assigned a priority number of 15 on a scale of 1 to 18 (1C being highest priority), using a system derived by the USFWS (USFWS 1983, USFWS 1999a).

The statewide coot population is estimated to range between 2000 and 4000 birds, with Kaua'i, O'ahu, and Mau'i supporting 80 percent of these birds (Engilis and Pratt 1993). After O'ahu, Mau'i Nui's population is the largest in the state with Kealia and Kanaha Ponds supporting most of the coots (USFWS 1999a). Data from State Department of Land and Natural Resources waterbird surveys from 1976 to 1996 indicates a stable population trend (Figure 2-2) (USFWS 1999a).

Locomotion

Hawai'ian coots are adept at various types of locomotion. Coots are skillful at walking or running rapidly either on land or across water by Splattering (Pratt and Brisbin 2002). When traversing on land, the head is nodded in sequence with foot movements. Coots actively walking/running often undertake a hunched-back posture. Flight consists of strong and direct movements following an extended period of Splattering. Most flights are brief and <5 m in altitude unless addition elevation is necessary to avoid obstacles (Pratt and Brisbin 2002). Coots are also strong swimmers despite lobed toes that are not as efficient as full interdigital webbing for propulsion. Coots display head movements while swimming similar to those as when walking. Coots also have specialized muscles for underwater propulsion that aids in diving. Coots often dive by leaping into the air, clearing the water in an arc, pressing wings close to body with the head entering as the feet leave the water (Bent 1926, Pratt and Brisbin 2002).

Habitat

Hawai'ian coots nest on open fresh and brackish ponds, on shallow reservoirs, irrigation ditches, and small openings of marsh vegetation (Udvardy 1960, Shallenberger

1977). Wetlands with robust emergent plants with open, fresh water which is usually less than 1 m deep have the highest densities of nesting pairs (Byrd *et al*. 1985). Optimum nesting habitat includes a thorough interspersion of clumps of robust emergent and open water (Gullion 1954, Miller and Collins 1954, Ryder 1961, Vaa *et al*. 1974) reaching an overall ratio approximately 50:50 (Weller and Fredrickson 1974). Coots are generalists. Coots typically forage in water less than 30 cm (12 in) deep, but can dive in water up to 120 cm (48 in) deep. Suitable habitats include ponds sufficiently large (0.1 to 0.2 ha) for coots to take off and land (Weller and Spatcher 1965), but not so large that protection from wind is lost (Fredrickson 1977, Harris and Marshall 1957).

Nesting Associated with Water and Other Nests

Hawai'ian coot nests are most often found on water's surface at the outer margin of emergent vegetation around relatively deep bodies of water (Byrd *et al.* 1985). Nests are anchored to dense floating algal mats or stems of bulrush, cattail, indian fleabane, or pickleweed so the nest could rise and fall. Hawai'ian coots also generally avoid dense clumps of emergent vegetation as nest sites. Most nests were placed on the fringes of bulrush with a relatively low stem density, yet the height of vegetation varied considerably (Byrd *et al.* 1985). Hawai'ian coots also have been observed nesting in open water where they build floating nests.

Few studies have investigated the nesting densities of Hawai'ian coots. In 1976 and 1978, the average distance between active coot nests was 27 m and 25.5 m respectively at Kealia Pond. During these same years, nests were as close together as 7 m and 13.5 m respectively at Kealia Pond (Ueoka *et al.* 1976, Dougherty *et al.* 1978, Byrd *et al*. 1985). In comparison, an average nearest-neighbor distance of about 50 m was documented for 577 American coot nests in a Saskatchewan study area (Sugden 1979).

Nest Characteristics

Hawai'ian coot nests are large platforms composed of a massive pile of vegetation approaching 1 m thick and 0.6 m in diameter, usually partially floating and mostly underwater (Pratt and Brisbin 2002). The nest bowl is about 31 cm outside diameter, 16 cm inside diameter, and 6 cm deep with a rim about 7.5 cm above the water (Schwartz and Schwartz 1952). Construction materials include bulrush, Hilo grass, and pickleweed (Pratt and Brisbin 2002). Bulrush was favored as nesting material, but Indian fleabane and California grass were other nesting materials (Byrd *et al.* 1985). Hawai'ian coots may construct a ramp on one side of the nest that is used by birds entering and leaving the nest (Pratt and Brisbin 2002).

Chronology

Timing of nest initiation corresponds with seasonal weather conditions (Byrd *et al.* 1985, Engilis and Pratt 1993). The predominant period for nesting generally occurs from March through September, although some nesting occurs all months of the year (Shallenberger 1977). Two breeding peaks for Hawai'ian coots were discovered on Moloka'i as either November-February or June-October (Coleman 1978). At 'Aimakapā Pond on Hawai'i nesting occurred in all months except January and November with peaks in May and July (Morin 1998).

Hawai'ian coot eggs are considered indistinguishable from those of American coot (Henshaw 1902, Pratt and Brisbin 2002). Eggs are light tan, speckled with light to dark brown and purple inflections. A typical clutch is 1 to 10 eggs and averages about 5 (Byrd *et al*. 1985, Morin 1998). Clutches of Hawai'ian coots are generally smaller than those of American coots.

Coot incubation periods are difficult to determine because incubation may begin after the first egg is laid or it may be delayed until after the second or subsequent eggs are laid (Gullion 1954, Sooter 1941). Reported incubation periods for Hawai'ian coots vary between studies. Shallenberger (1977) provided a tentative range of 23 to 27 days while Ueoka *et al*. (1976) and Dougherty *et al*. (1978) reported incubation periods of 25 and 24.7 days in two different years at Kealia Pond. Depending upon timing of egg laying, chicks may hatch synchronously or asynchronously but at a generally uniform rate. Young chicks are precocial. Once dry, the young are able to leave the nest and begin to swim (Pratt and Brisbin 2002). Chicks accompany the adults, but little to no information is available on parental care.

Causes of Mortality

Predators, disease, and agricultural chemicals influence success of the Hawai'ian coot. Berger (1981) reported predation of adults by feral cats, dogs (*Canis familiarus*), and introduced mongoose. Indigenous Black-crowned Night-Herons (*Nycticorax nycticorax*) along with introduced Cattle Egrets and large fish may also be a serious predator on young coots (Pyle 1985, Morin 1998). Botulism outbreaks have been recorded throughout the 1990's in several major Hawai'ian Island wetlands. Adverse affects of agricultural chemicals was suggested by Schwartz and Schwartz (1952), but no connection has been documented between population declines and pollution.

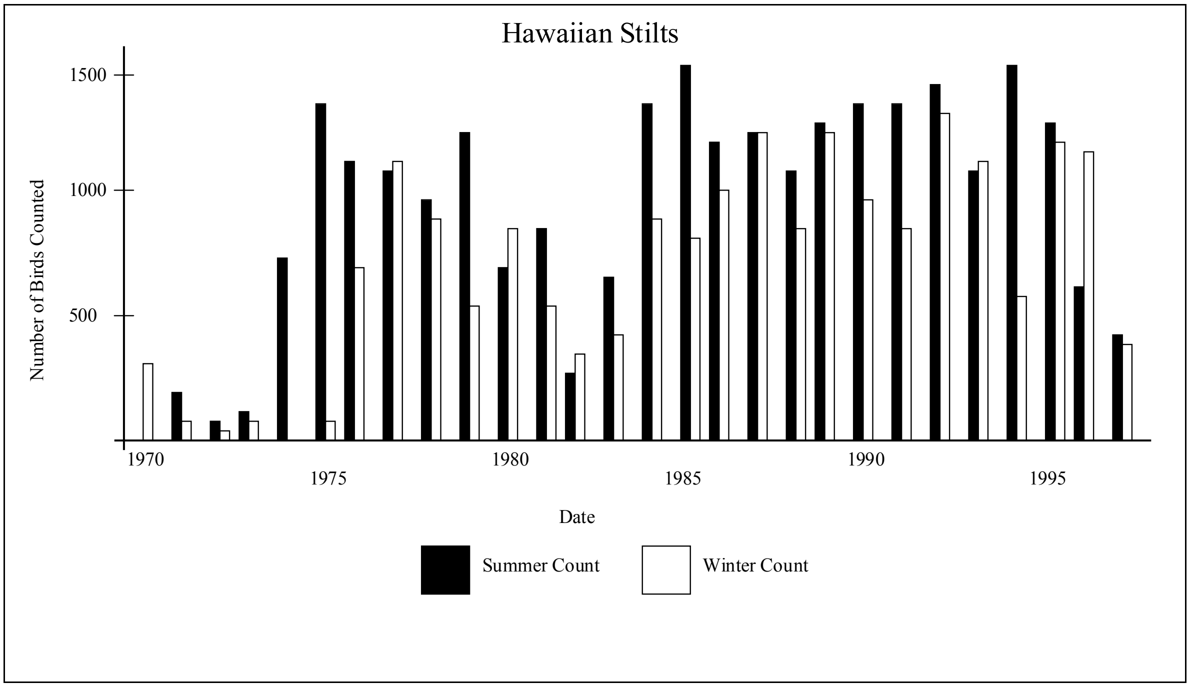

Figure 2-1. Hawai'ian stilt counts at wetland habitats in the Hawai'ian Islands from 1974 to 1997.

Source: USFWS 1999a

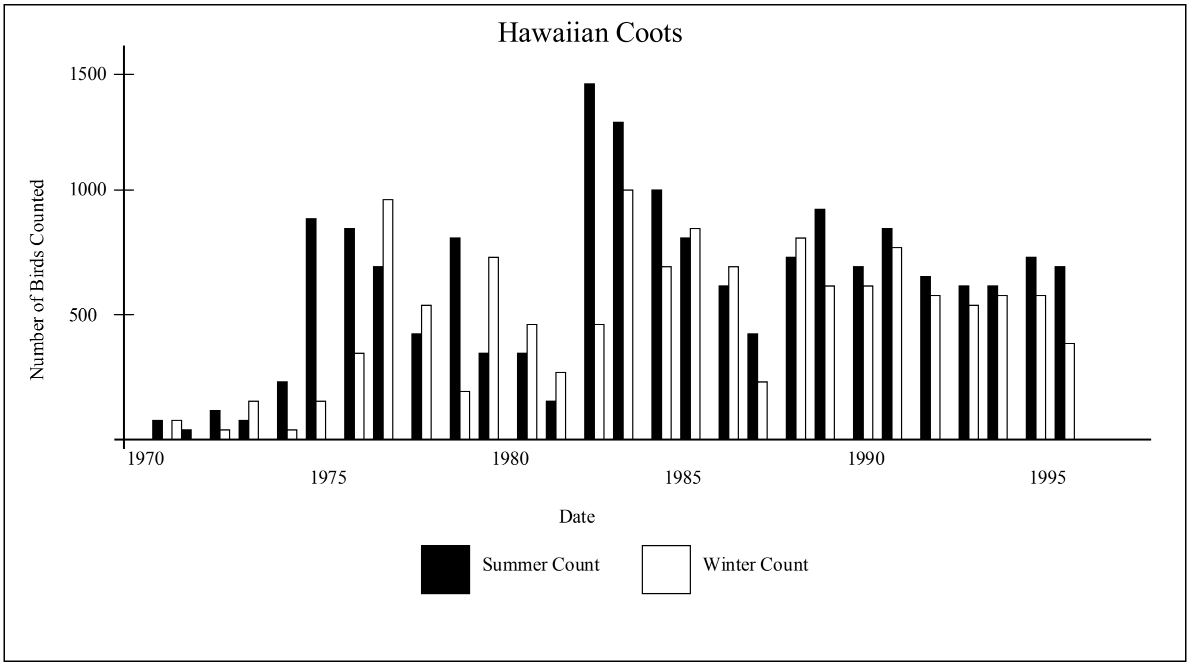

Figure 2-2. Hawai'ian coot counts at wetland habitats in the Hawai'ian Islands from 1974 to 1997.

Source: USFWS 1999a

Study Area: Kealia Pond National Wildlife Refuge:

The Hawai'ian Archipelago developed almost wholly by volcanic activity (MacDonald *et al.* 1983). At some time millions of years ago, a series of fissures opened a long, narrow, northwest-trending zone in the ocean floor (MacDonald *et al.* 1983). Molten rock emanated at intervals from the interior of the earth along those fissures, hardened, and gradually formed layer upon layer, to build the mountains. The county of Mau'i is part of a huge volcanic mastiff consisting of at least six major and one minor volcano. The island of Mau'i consists of two of the six major volcanoes within the county. The older one, West Mau'i, formed 1.3 million years ago and the younger, Haleakala or East Mau'i, formed 0.75 million years ago (Juvik and Juvik 1998). The gently sloping area that lies between the two volcanoes is the Mau'i isthmus. The isthmus was formed when lava flows from Haleakala banked against the previously developed West Mau'i volcano (MacDonald *et al.* 1983). This isthmus is presently known as the Kealia Floodplain.

Kealia Pond National Wildlife Refuge encompasses 283 ha of Mau'i County, in Hawai'i. The refuge lies on the leeward side of the isthmus between the East and West Mau'i mountains and rises adjacent to the shores of Maalaea Bay within the southern extent of the Kealia Floodplain. In the spring of 1970, interests for development of this wetland area converged on Kealia Pond. Active water-related interests included: harbor development (U.S. Army Corp of Engineers), commercial aquaculture (Fish farms Hawai'i), shrimp-laboratory (Mau'i Office of Economic Opportunity), and a waterbird refuge (U.S. Bureau of Sport Fisheries and Wildlife, Maciolek 1971). Obvious conflicts among these interests and the irreversible modifications of harbor dredging led to the initiation of several aquatic ecosystem studies.

Since 1970, aquaculture was established, harbor plans were abandoned, the shrimp laboratory was withdrawn due to site unsuitability, yet the refuge proposal continued under official review. Preliminary study suggested these areas had considerable natural value and public use potential. Therefore, after years of meetings and dealings, a perpetual agreement between the USFWS and HC&S, a sugar cane company, was signed in 1992 for the establishment of a National Wildlife Refuge.

Kealia Pond National Wildlife Refuge is one of six refuges in Hawai'i and one of two significant waterfowl/shorebird sanctuaries in Mau'i (Figure 3-1). It is an open space, central to 3 principle residential areas: Kihei-Makena, Kahului-Wailuku, and Lahaina-Kaanapali (Maciolek 1971). The Kealia-Maalaea area contains two interrelated primary aquatic ecosystems; Kealia Pond and the adjacent inshore waters of Maalaea Bay. A third system, hinterland drainages, also must be considered because its runoff waters strongly influence the two primary systems (Maciolek 1971). Waiakoa gulch, Pohakea, Kolaloa and Waikapu streams serve as the primary inputs of the system. Waiakoa gulch drains a portion of West Haleakala. Waikapu stream drains the southeastern part of the West Mau'i Mountains and is the principal inflow to Kealia Pond, and therefore provides important inputs to the western part of Maalaea Bay (Maciolek 1971).

Water levels in Kealia Pond vary seasonally. Surface area ranges from 20 to 162 ha, but in some years the pond is completely dry. Kealia Pond is believed to have been formed naturally by wind and waves. The site serves as a settling basin for a 145 km^2 watershed from the West Mau'i Mountains. Anecdotal information reveals that Kealia Pond was a permanent water body with 122 to 152 cm of water, before European settlement. Upstream agricultural practices contributed to the basin's degradation and agricultural practices resulted in seasonal flooding since the mid-1920's. Presently, the pond varies in depth from 30 to 152 cm and is laden with silt from agricultural runoff. The pond acts as a deflation plain that traps sediments during rainfall events, thus protecting water quality of the (Maalaea) Bay, an important site for sea life and tourism (Maciolek 1971).

Kealia, meaning the salt-encrusted place, has been an important source of fish and salt for Hawai'ians for over 400 years (USFWS 1995). During the dry summer months, the pond recedes to half its winter pool or completely dries, leaving a light salt crust residue (gypsum marginally and halite centrally) along its margins (Maciolek 1971). The summer drawdown and drying results in oxidation of the pond bottom which releases nutrients and is likely the reason for its high productivity. The prevailing trade winds remove pond sediments from the dried basin which prevents the pond from prematurely filling with sediments.

The climate of the leeward side of Mau'i is noticeably stable (Figure 3-2). Temperature remains consistent throughout the year with a mean low temperature of 80 ^{o}F in January and February and a mean high temperature of 87 ^{o}F in August and September. The mean precipitation is 38.30 cm per year (Juvik and Juvik 1998). Over three quarters of the precipitation falls during the winter months between December and

March. The distribution of precipitation over the past 55 years illustrates a peak in January followed by a continual decline through the spring and a dry summer. However, within and among years the amount and distribution of precipitation varies.

Kealia Pond National Wildlife Refuge's primary pool has undergone limited management since the refuge's inception. The majority of Kealia Pond National Wildlife Refuge lacks an infrastructure that allows water manipulation. Thus, water levels in Kealia Pond and Maalaea Flats are dependent upon inputs from perennial streams. Present management consists of managing water levels in the headquarters fish ponds and pumping water into Kealia Pond to reduce the potential for complete drying. These management activities benefit endangered Hawai'ian waterbirds, as well as migratory waterfowl and shorebirds, yet water management is often problematic. Precipitation in Mau'i County is variable (Fig. 3-3), and contributes indirectly to water levels at Kealia Pond National Wildlife Refuge through the aforementioned perennial streams. Water inputs are variable and flow frequency is often based on agricultural demands within the Kealia Floodplain and rainfall in the surrounding mountain ranges. Runoff waters, reaching the refuge from the highlands of both East and West Mau'i, flow through Kealia Pond and enter Maalaea Bay through a discharge at Palalau. Flow through this discharge point is compromised by the presence of a natural sand plug. Because of the sand plug, water levels at Kealia Pond National Wildlife Refuge remain stable and contribute to reduced productivity. Only at times of low tide and significant water pressure from the pond will the sand plug breach allowing the pond to drain. Otherwise the plug must be removed by hand or by machine through a permitting process to facilitate drainage.

Because of the inability to control water levels, conditions are often not ideal for waterbird nesting, foraging, or plant germination.

Soils on the Kealia Pond National Wildlife Refuge, as described by the Natural Resource Conservation Service, are Kealia silt loam. After heavy rains, puddling occurs in low areas. After drying and evaporation, salts accumulate on the surface. A representative soil profile, from within the refuge, consists of a dark reddish-brown silt loam about 7.6 cm thick with stratified layers, of silt loam, loam, and fine sandy loam with depth (Nakai and Mayer 2001). A brackish water table occurs at a depth of 30 to 101 cm. The soil is a poorly drained with a high concentration of salts, and is moderately alkaline. A more detailed soil survey of seven core samples on Kealia Pond National Wildlife Refuge was taken in September 2001. Surface horizons for all seven cores were fine textured. Two cores from west of the pond outlet has surface horizons of silty clays. In the remaining five north shore cores, surface horizons were silty clay loams or silt loams. Sites located to the west and northwest had surface horizons with a thin platy structural characteristic of wind deposition. Coarser textured sandy loam was encountered at all sites about 56 cm from the surface but varied from 41 to 61 cm (Nakai and Mayer 2001).

The dominant vegetation reflects management for stable water systems and increased soil salinities in Kealia Pond. Pickleweed, California grass, indian marsh fleabane, and California bulrush cover most of the outer edges of Kealia Pond. Hawai'i "makai" (*Scirpus maritimus* var. *paludosus*) and Sprangletop (*Leptochloa uninerviai*) occur in patches and along the fringes of the pond. The plant community composition accurately reflects the lack of vegetation management.

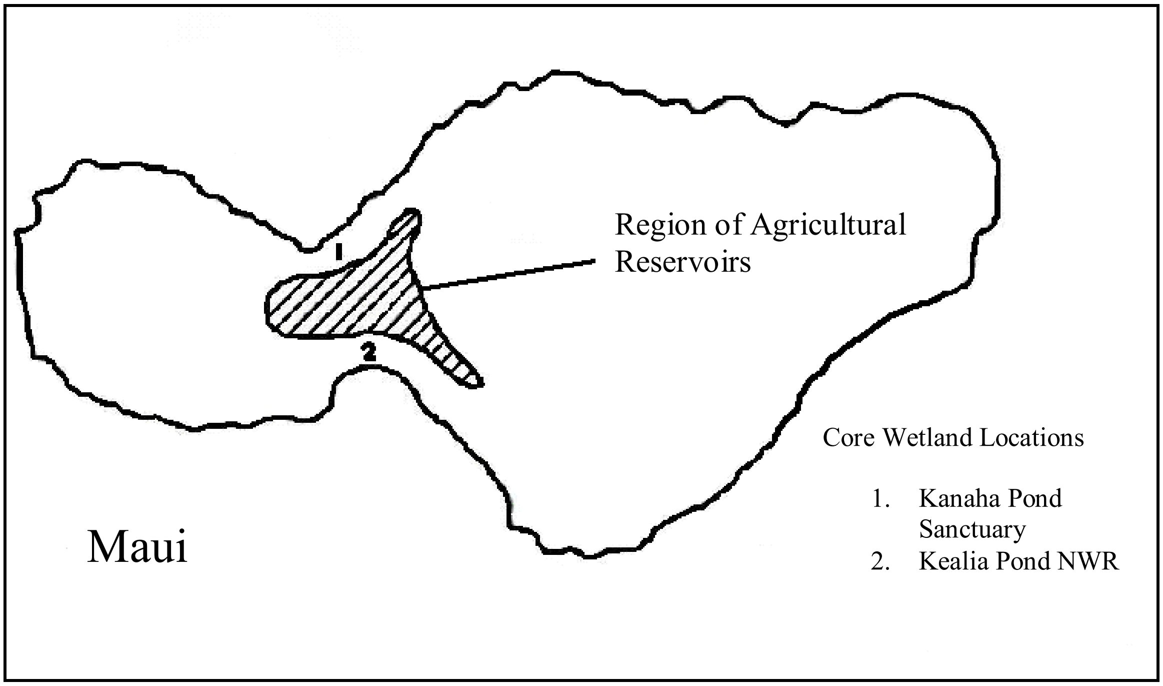

Figure 3-1. Core wetland localities on the island of Mau'i.

Source: USFWS 1999a

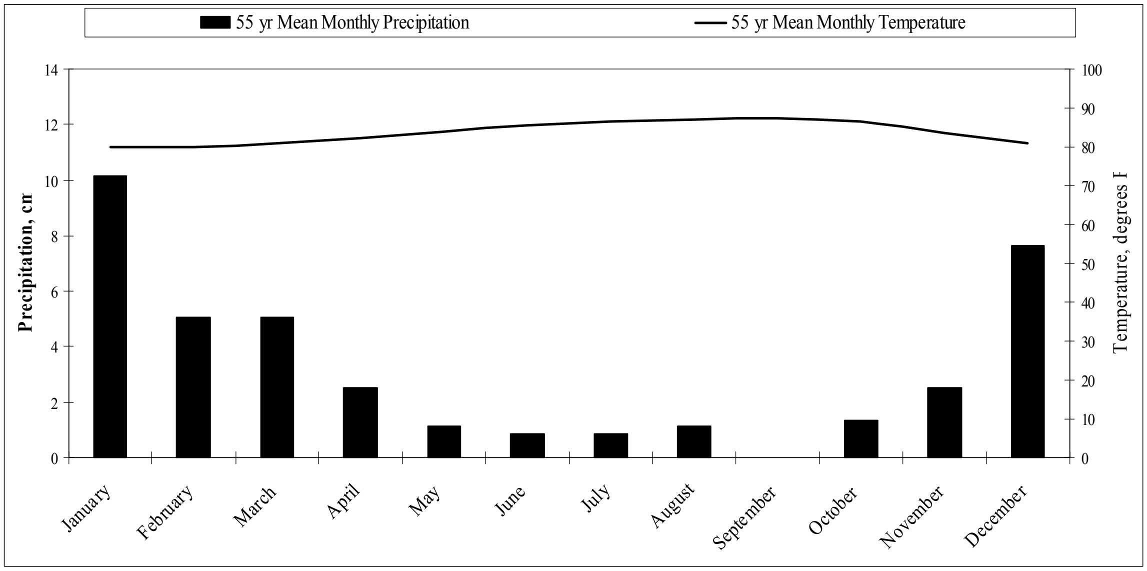

Figure 3-2. The 55 year monthly mean precipitation and temperature for Kihei, Mau'i.

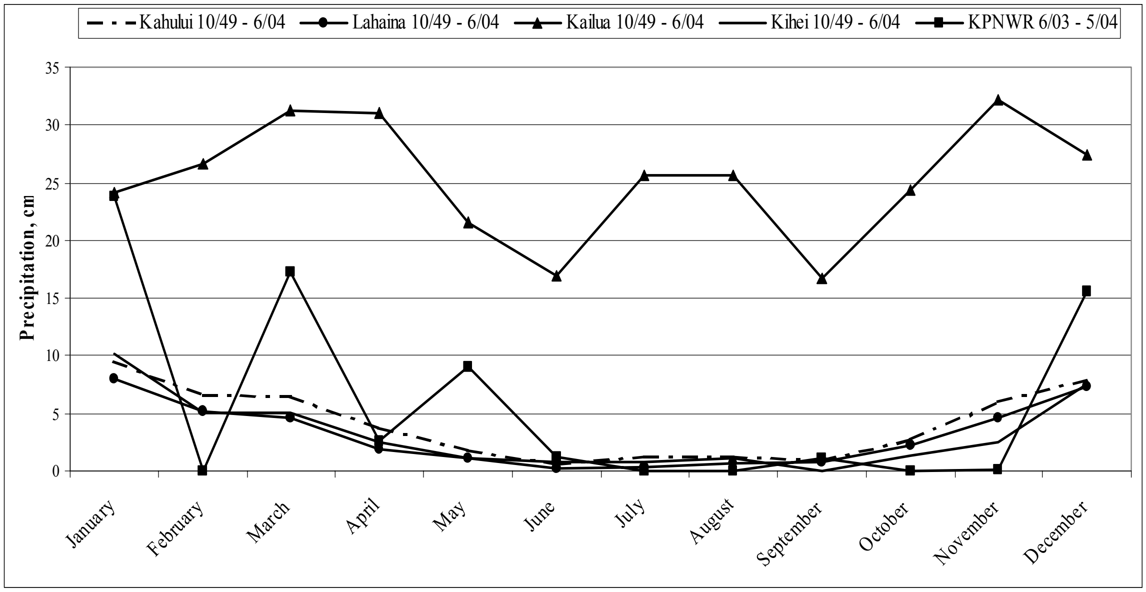

Figure 3-3. Mean monthly precipitation for different zones within the Kealia Floodplain of Mau'i, Hawai'i from 1949 to 2004, and precipitation at Kealia Pond National Wildlife Refuge from 2003-2004.

Methods:

Nest Searching

In 2004, systematic nest searches were conducted daily from January to July through habitats on the north shore of Kealia Pond. Searches focused on the edges of tall robust vegetation. Densely vegetated areas, patches of vegetation, and mudflats were searched by wading. Sparsely vegetated areas and vegetation fringes in deeper water usually were searched by kayak. Areas detected during surveys where birds flushed or defended territories were searched systematically. New nests also were discovered during nest monitoring, vegetation sampling, and water monitoring activities conducted by refuge staff.

Nest Monitoring

Once discovered, nests were marked by placing florescent flagging on a bamboo stake, approximately 5 m away from the nest to avoid attracting predators. Each nest was GIS referenced for mapping. Nest dimensions and vegetation characteristics were measured when a nest was discovered. The number, size, and mass of eggs were taken during each nest visit. Most nests were monitored two times a week. Seven days was the longest time between nest visits. Occasionally, a greater time between visits was required because of weather.

Habitat Characteristics

Information about vegetation and microhabitat characteristics at the nest sites assisted in understanding how Hawai'ian stilts and coots used habitats at Kealia Pond National Wildlife Refuge. Variation in nest metric suggest how nesting birds adapt to conditions in wetlands where the proportion and distribution of exotic, invasive , and/or native vegetation and its structure vary based on abiotic factors that are different from natural settings. I measured nest diameter, thickness, height above water surface, water depth at the nest, as well as the type of vegetation used for the nest substrate along with the height of surrounding vegetation to obtain assess of how nest and habitat characteristics change with treatments(Appendix 1). During the nesting season, vegetative obscurity was measured using a cover board (3 cm X 150 cm) (Fig. 4-1) that was marked by black patches alternating every 10 cm on the pole. The vegetation density was determined by the number of 10 cm areas that were less than 25% visually obstructed. The obstruction values recorded were 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, and 150. The obstruction values were read from a standard 4 m distance at magnetic North (Robel *et al.* 1970). After taking the initial reading, three additional readings at 90-degree angles from the original bearing and at the same distance were recorded. These four readings were averaged for a vegetative height measurement for the nest site.

Measurement of Eggs

Egg metrics provide insight into the nutritional status of nesting birds. Variation in egg size, mass, and numbers reflect habitat conditions that might influence successful nesting. Eggs were marked to assure accuracy in repeated measurement with an odorless felt marker (Sharpie) according to the order in which they were laid when possible. Egg width and length were recorded utilizing a plastic dial caliper and mass was measured utilizing a 60 g Pesola® Micro-Line spring scale during each visit to the nest until eggs hatched or the nest failed (i.e., abandonment, flooding, or predation).

Vegetation Treatments

In 2003, mowing and tillage treatments were implemented in monotypic stands of pickleweed to determine the potential to increase interspersion of open water and to promote native vegetation such as makai sedge in Kealia Pond. Treatments were implemented in strips (50 m wide) along the elevation gradient from the open water at the lowest elevation to a higher elevation at the wetland edge or where woody vegetation was too large for treatment with the available equipment. Two mowing and tillage treatment strips each with a control were replicated four times and were positioned side by side in monotypic stands of pickleweed (Fig. 4-2). For a randomized block design, strips were randomly assigned to a treatment type or a control within block. Using GPS mapping and survey maps, a baseline was established along the edge of the northern shore of Kealia Pond. The parameters of this baseline were placed into a random numbers program to generate four transects. In one treatment the entire area was mowed and roto-tilled to destroy all pickleweed. These treatments were designated as unclumped. The second treatment was mowed and roto-tilled to destroy all pickleweed, but clumps (3 to 5 m in width and 10 to 12 m in length) were left across the elevational gradient. These treatments were designated as clumped. Treatments consisted of mowing followed by two passes with a Niplo roto-tiller equipped with s-shaped blades at a depth of 13 cm. Mowing of the treatments began on 28 July 2003 and ended on 4 August 2003. Tilling was performed from 6 August 2003 through 9 August 2003. Two passes with the roto-tiller were required to eliminate residual pickleweed. Control plots consisted of equal sized strips within the monotypic pickleweed immediately adjacent to the treated strips.

Plant Growth Characteristics

In summer 2004, vegetation was sampled to examine plant growth characteristics of invasive species in vegetation treatments. Quadrats (N = 29) were randomly selected within a single treatment. A rectangular sampling frame (50 cm X 100 cm) (Fig. 4-3) was used as the quadrat size. Total stem counts were recorded of all species present within the quadrat. Additional variables were recorded for the two invasive species; indian marsh fleabane and pickleweed. These variables consisted of plant origin (i.e., seed or residual growth), plant height or stolon length, root diameter, root length, number of shoots, and length of subsequent shoots.

Waterbird Monitoring

Waterbird monitoring was important in assessing habitat and location of use throughout the year. In conjunction with refuge staff, I monitored waterbirds along established survey transects of Kealia Pond beginning in September 2003 through July 2004. Waterbird surveys were performed every first and third Thursday of the month at Kealia Pond National Wildlife Refuge. Data collected included species, location, percent cloud cover, and wind direction and speed. Bimonthly surveys provided total bird counts at Kealia Pond National Wildlife Refuge relative to time of year.

In addition to bi-monthly surveys, spot scans were performed beginning in September 2003 through July 2004. Spot scans were conducted to determine the timing, magnitude, and the nature of use by stilts and coots. Four areas of known bird use were identified in spring of 2003. These locations within the refuge along with treatment areas were surveyed weekly to provide information on bird distribution. Data collected included broad habitat use, location, behavior, and water depth categories in relation to body size (Appendix 2).

Data Analysis

A Multivariate analysis of variance (ANOVA) was used to determine plant growth characteristic factors of significance. Mean height of invasive species was calculated and a means comparison was employed for each factor to assess growth differences between pickleweed originated from seed *vs*. residual growth. A mean plant composition per quadrat also was calculated.

Waterbird data were analyzed with SYSTAT. Variables such as nest fate, clutch size, nest setting and nest characteristics were analyzed and means were reported. Waterbird behavior data were organized into tables and percentages of utilization were reported. Daily nest success was calculated (Mayfield 1961, 1975, Hensler and Nichols 1981, Martin and Geupel 1993) as described by Mayfield (1975). Linear regression was used to estimate the pattern of mass loss during incubation in stilts and coots.

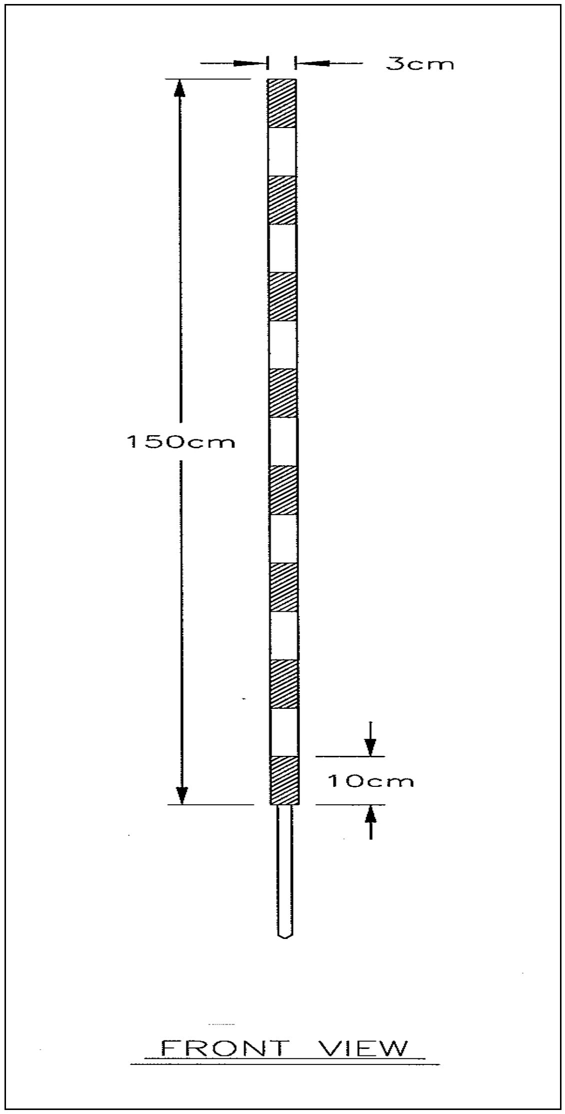

Figure 4-1. Cover Board Schematics

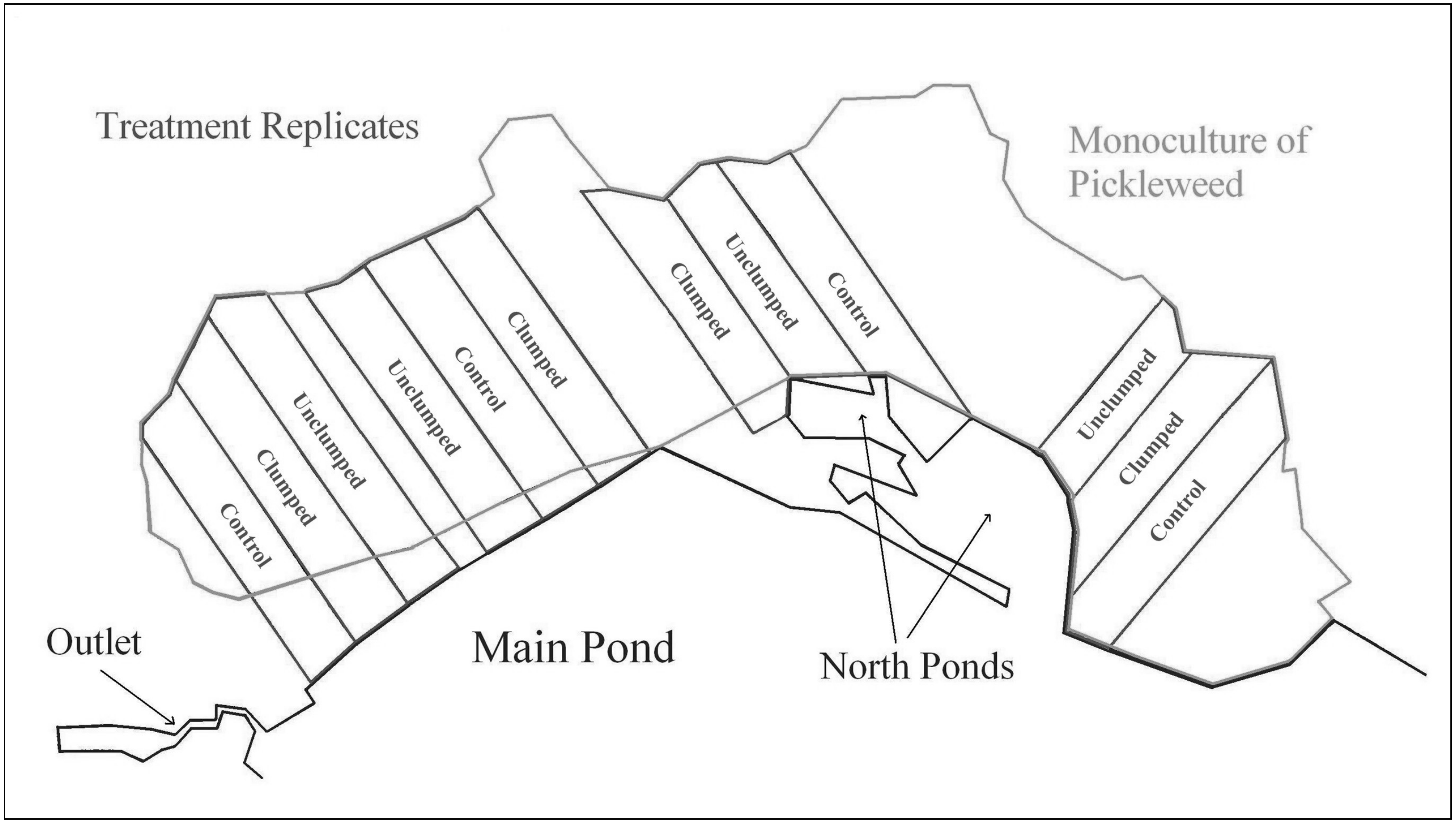

Figure 4-2. Diagram of replicates and treatments on the north shore of Kealia Pond National Wildlife Refuge.

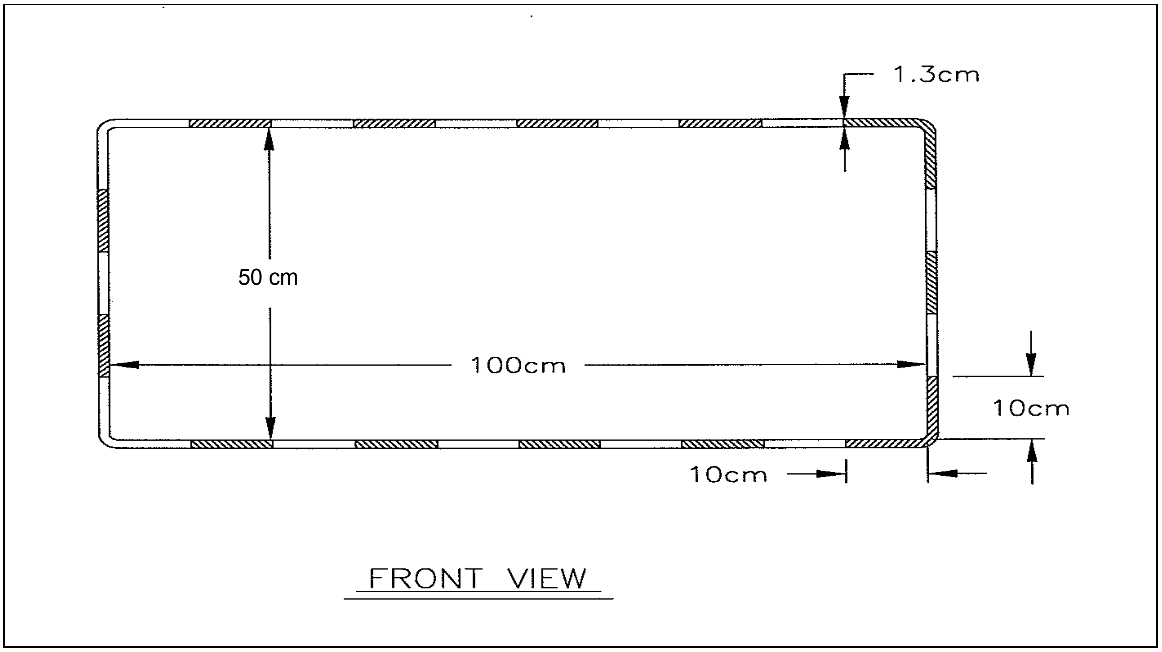

Figure 4-3. Rectangular Sampling Frame Schematic

Habitat Selection and Nest Characteristics – Results and Discussion:

Nest Distribution

In 2004, 32 Hawai'ian stilt and 69 Hawai'ian coot nests were found on the north shore of Kealia Pond. The majority of the stilt nests (27 out of 32 nests) were found within or on the fringes of the north shore vegetation treatments (Fig. 5-1). The majority of the coot nests were confined to areas dominated by dense stands of makai sedge (Fig. 5-2). The distribution of coot nests varied throughout the season. Early nesters seemed to disperse within patches of sedge in smaller corridors and trails. Later in the season when water levels fluctuated greatly, nests were aggregated in patches of 75:25 makai and pickleweed at higher elevations.

Nest Site Settings & Characteristics

In 2004, there were 32 nesting attempts by Hawai'ian Stilts on the north shore of Kealia Pond National Wildlife Refuge. The majority of nest sites consisted of sparse patches of pickleweed within large expanses of mudflat. Mean vegetation height at the nest was 19.1 cm (SD = 14.4). Visual obscurity at most nest sites consisted of a dense patch of low growing vegetation (3.6 cm, SD = 8.3).

Of the 32 stilt nests observed, 13 nests were constructed at a distance greater that 5 m from water. The remaining 19 stilt nests were constructed a mean distance of 0.3 m (SD = 0.6) from the water's edge which is less than the reported distance of 1.49-5.61 m by Coleman (1981) in O'ahu, Hawai'i. Mean water depth was 1.8 cm (SD = 2.8). The proximity of nests to cover was variable. Four stilt nests were constructed at a distance greater than 5 m from the nearest cover patch. The remaining stilt nests (N = 28) were 0.4 m (SD = 1.1) from surrounding vegetation.

The nest substrate selected by stilts was similar to the surrounding vegetation. Most nests were constructed (N = 29) of live and dead pickleweed. The remainder of the nests were constructed of sprangletop (N = 2) and mud (N = 1). The nest characteristics for stilts during the 2004 field season were comparable to those in the literature (Coleman 1981). However, some measurements fell outside of the range of those previously reported. Nest measurements were taken upon time of nest discovery and were taken only once. Outer mean nest diameter of 23.5 cm (SD = 5.4) was comparatively larger and mean cup depth of 2.5 cm (SD = 0.7) was shallower than previously reported values (Coleman 1981). Mean inner nest diameter or mean cup diameter was 11.9 cm (SD = 1.9). Additionally, mean nest height of 4.1 cm (SD = 2.7) in my study was comparatively larger than values reported in the literature (Coleman 1981).

Hawai'ian Coots attempted 69 nests on the north shore of Kealia Pond National Wildlife Refuge. The majority of nest sites consisted of sparse to moderate patches of pickleweed and dense patches of makai sedge. Mean vegetation height at the nest was 100.5 cm (SD = 26.0) with a mean vegetation height of 65.7 cm (SD = 20.5) occurring above the water surface. Dense patches of tall emergent vegetation at most nest sites contributed to a mean visual obscurity of 50.2 cm (SD = 35.1). Of the 69 coot nests observed, all nests were constructed in or over the water. Mean water depth was 37.8 cm (SD = 13.8).

Construction material for coot nests was comprised primarily of vegetation in close proximity of the site selected.   Most nests were constructed (N = 67) of live and dead makai sedge. The remainder of the nests were constructed of dead pickleweed (N = 2). The nest characteristics, for coots, during the 2004 field season were comparable to those in the literature (Table 5-1) (Byrd et al. 1985, Schwartz and Schwartz 1952). An outer mean nest diameter of 29.6 cm (SD = 4.3) was smaller and mean cup depth of 5.0 cm (SD = 1.7) was shallower than previously reported (Byrd et al. 1985, Schwartz and Schwartz 1952). Mean inner nest diameter or mean cup diameter was 16.3 cm (SD = 2.4) which is similar to previously reported values (Byrd et al. 1985, Schwartz and Schwartz 1952). Mean nest height was 52.0 cm (SD = 13.9) and nest height above water was 14.1 cm (SD = 6.3).

Nesting Attempts

In 2004, 67 Hawai'ian Coot and 32 Hawai'ian Stilt nests had eggs at the time of discovery and all 99 nests were monitored. Measurements of 320 coot and 123 stilt eggs were taken from these nests. During 2004, coot eggs measured 47.8 X 33.2 mm and stilt eggs measured 44.3 X 31.8 mm.   The mean clutch size for coots was 4.8 (range 1 to 9 eggs) and mean clutch size for stilts was 3.8 (range 2 to 5 eggs). The mean clutch sizes for both species fell within the previously documented means (Table 5-2). Additionally, stilts were observed dropping eggs in areas without scrapes and laying a supernormal clutch. Supernormal/supernumerary stilt clutches were noted previously by Coleman (1981).

Incubation

Although the length of incubation for Hawai'ian stilts and coots has been estimated at approximately 25 days in the literature (Berger 1967, Ueoka *et al.* 1976, Shallenberger 1977, Dougherty *et al*. 1978, Coleman 1981, Robinson *et al.* 1999), changes in egg mass during waterbird incubation has been poorly documented (Weller 1961, Ziebell 1990, Fredrickson 1996). Mass loss during incubation varies among species, but the loss is approximately 11-18% of the fresh egg weight (Manning 1982, Rahn and Ar 1974, Ashkenazi and Yom-Tov 1997, Nelson 2003). The general rule during avian incubation is that water is lost over time, with egg mass decreasing at a constant rate (Manning 1982, Rahn and Ar 1974, Saunders and Smith 1981, Nelson 2003). Contributing to variability in this general pattern of mass loss is the microclimate inside and around the egg. The size of egg, age of the incubating adult, type of nest, and climatic conditions (humidity) can cause rate of mass loss to differ daily, among eggs, and/or among clutches (Keppie 1984, Manning 1982, Rahn and Ar 1974, Woodall and Perry 1981, Nelson 2003).

In 2004, 582 measurements were taken of 320 coot eggs and 323 measurements were taken of 123 stilt eggs. Approximately 9.07% of the mean fresh egg mass was lost during incubation for coots and 14.32% for stilts. A constant rate of mass loss was observed as linear regression accounted for 78.29% of the mean daily egg mass during incubation for coots (fresh egg mass to 25 days old) and 82.63% for stilts (fresh egg mass to 23 days old) (Figures 5-3 & 5-4). Variability among eggs and within the daily mass was observed and expected. Variability in egg size, humidity, and timing of incubation were the potential causes for the range in egg mass for each day of incubation.

Nest Success

A successful Hawai'ian coot or stilt nest was defined as having at least one fledgling. Most nest failures for both species occurred during the incubation period. Nest success was calculated for both species during the incubation period. Hawai'ian coots nesting on the north shore of Kealia Pond lost 26 nests over 641.5 nest exposure days. Nest success equated to 35.55% based on a 25 day incubation period. Hawai'ian stilts nesting on the north shore of Kealia Pond lost 14 nests over 365.5 nest exposure days. Nest success equated to 37.67% based on a 25 day incubation period.

Causes of Failure

Nest failure was determined from evidence at the nest. Based on this evidence failure occurred for a variety of reasons including: weather, precipitation, predation, changing water levels, and abandonment. The influence of weather contributed substantially more to nest loss than all other factors combined during 2004 and included direct and indirect effects. The winter and spring of 2004 were the wettest on record for Mau'i over the last twenty years. The combination of trade winds and rain resulted in conditions that caused five coot nests to be overtopped with water. Eggs in these nests spilled into the water. The remaining 10 coot nest and 8 stilt nests were flooded when precipitation caused flooding along the primary tributaries of Kealia Pond. Flooding caused approximately 58% of nest failures for Hawai'ian coots and 57% for Hawai'ian stilts (Table 5-3). These flooding events accounted for 47% of total egg loss for coots and 56% for stilts (Table 5-4). Failed nests were flooded because the birds could not add material to the nests quickly enough to keep the nest bowl above the rising waters.

Predators caused 43% of nest failures and 41% of total egg loss for stilts, but predators had no impact on coots. Predated nests were intact, but all eggs were missing. Mammalian tracks of domestic cat and mongoose were present around predated nest sites. These species have been identified as predators in other studies (Griffin *et al.* 1990, USFWS 1999a).

Ten of 26 failed coot nests were abandoned and all were in mid incubation. Abandonment, calculated in the absence of flooding, contributed to 38% of all coot nest and egg failures. Possible factors contributing to abandonment were inexperienced nesters or disturbance caused by the presence of staff or observers in the field. No information was available in the literature for comparison of abandonment rates at other sites in Hawai'i.

Comparisons to previous studies

Examining the characteristics and settings of nests provided an indication of the availability of suitable resources at Kealia Pond National Wildlife Refuge during the breeding season. The location, structural properties, and plant types were described for nest sites (Weller 1999) to better understand the habitat requirements of nesting endangered waterbirds at Kealia Pond National Wildlife Refuge.

Hawai'ian coot nests were distributed throughout makai sedge along the fringes of Kealia Pond and treated areas. Hawai'ian coots utilized makai sedge as the predominant nesting material (Table 5-5), a trend observed at Kealia Pond National

Wildlife Refuge which differs from other Hawai'ian wetlands. Among semi-floating coot nests observed at other sites in Hawai'i, California bulrush, cattail, indian marsh fleabane, Hilo grass, kiawe twigs (*Prosopis pallida*) and pickleweed were the predominant nesting materials (Pratt and Brisbin 2002, Byrd *et al.* 1985, Perkins 1903). The utilization of makai sedge at Kealia Pond National Wildlife Refuge for nesting may be because of the presence of makai in combination with the limited combination of California bulrush and cattail along the protected north shoreline where monotypic expanses of pickleweed are prevalent.

Nesting habitat utilized by Hawai'ian coots reinforces the importance of makai sedge for these endemic birds (Table 5-6). Ueoka *et al.* (1976) reported that nests constructed in habitats dominated by pickleweed were constructed of pickleweed, but lined with makai sedge. This suggests coots at Kealia Pond National Wildlife Refuge will gather preferred construction materials away from the nest if they are not readily available in close juxtaposition of the selected nest site.

Reproductive success was comparatively lower in 2004 compared to previous years (Table 5-7). Nest success calculated utilizing both apparent nest success and Mayfield method for nest success was comparatively lower than the range observed from 1996 to 2001. As in most years, flooding or drowning of nests was the greatest contributor to nest loss (Table 5-8). This may be attributed to the variable flow frequencies of the perennial streams draining through the refuge where there is considerable nesting but no infrastructure for water control. Abandonment was the second largest source of nest loss for Hawai'ian coots in this study. No previous data were available for comparison on nest abandonment.

Hawai'ian stilt nests were distributed throughout treated areas dominated by exposed mudflats. Hawai'ian stilts utilized pickleweed as the predominant nesting material (Table 5-9). This mirrors with results from nest monitoring between 1996 and 2001 at the refuge. Hawai'ian stilts use this pickleweed to line a nest scrape or build a platform to keep eggs out of the water. Hawai'ian coot nests were distributed throughout annual vegetation along the fringes of Kealia Pond and treated areas. Stilts on O'ahu utilized pickleweed more than any other substrate for nesting material (Coleman 1981).

Hawai'ian stilts utilized annual and perennial vegetation as nesting habitats (Table 5-10). Pickleweed was the predominant habitat in 2004 as in most previous years. However, the habitat in 2004 was restricted to low growing, sparse vegetation within large expanses of mudflats. On O'ahu, 35% of all stilt nests were next to live stands of pickleweed and 10% were adjacent to dead stands of pickleweed (Coleman 1981).

Reproductive success was lower in 2004 compared to previous years (Table 5-11). Nest success calculated utilizing apparent nest success and Mayfield method for nest success was lower than the range observed from 1996 to 2001. Flooding or drowning of nests was the greatest contributor to nest loss followed by predation at Kealia Pond National Wildlife Refuge in 2004 (Table 5-12). Similar studies on O'ahu revealed flooding as a major cause of nest failure contributing to 11% of total nest loss (Coleman 1981). On O'ahu, nest predation, in two separate studies, was also reported as a major cause of nest loss at James Campbell National Wildlife Refuge contributing to 26% (Coleman 1981) and 25.1% (Chang 1990) of the losses respectively.

Summary

Timing of endangered waterbird nesting in managed wetlands depends on water levels. Nests are easily flooded in areas where water levels can change rapidly because there is no water level control. High water levels at Kealia Pond National Wildlife Refuge may extend the nesting season for Hawai'ian coots by exposing annual vegetation at higher elevations but may delay nesting of Hawai'ian stilts because of a lack of suitable mudflat habitat. The inability to manipulate water levels at Kealia Pond National Wildlife Refuge contributed to overall nest loss by overtopping nests in 2004 and shortened the nesting season for Hawai'ian stilts because of lack of mudflat habitat.

Site conditions surrounding Hawai'ian coot and stilts nests provide information on the nesting requirements of endangered waterbirds at Kealia Pond National Wildlife Refuge. Nest site, clutch, and egg characteristics described for both species were similar to values previously reported for Hawai'ian endangered waterbirds.

Limited research has focused on the incubation period of these endangered waterbirds. Hawai'ian coot and stilt eggs lost mass at a constant rate during incubation. Mass loss in stilt eggs accounted for the expected percentage of the fresh egg weights while mass loss in coot eggs fell just below the expected percentage. This information provides a baseline for thought and comparison with additional data among years and locations.

Figure 5-1. Distribution of Hawai'ian stilt nests on the north shore of Kealia Pond National Wildlife Refuge during the 2004 nesting season.

Figure 5-2. Distribution of Hawai'ian coot nests on the north shore of Kealia Pond National Wildlife Refuge during the 2004 nesting season.

Table 5-1. Characteristics of Hawai'ian coot nests at various study areas in Hawai'i.

Location	Size of nest platforms (cm)		Water depth at nest (cm)	Source
	Outside diameter	Inside diameter		
Kakahaia (N = 6)	35.3 +/- 2.9	18.1 +/- 2.4		Byrd *et al.* 1985
Elsewhere in Hawai'i (N = 31)	30.8 +/- 0.9	17.0 +/- 0.8		Byrd *et al.* 1985
Throughout Hawai'i	31	16	7.5	Schwartz and Schwartz 1952
Amorient Aquafarms (N = 6)			60.8 +/- 6.6	Byrd *et al.* 1985
Elsewhere in Hawai'i (N = 26)			33.5 +/- 2.1	Byrd *et al.* 1985
Kealia Pond (N = 69)	29.6 +/- 4.3	16.3 +/- 2.4	14.1 +/- 6.3	Present study

Table 5-2. Comparison of Hawai'ian Coots and Hawai'ian Stilts clutch size on the north shore of Kealia Pond National Wildlife Refuge, Hawai'i in 2004 compared to previous studies.

Species and Source	Clutch Size		
	Mean	SE	N
Hawai'ian Stilts			
Present Study	3.8	0.11	32
Chang 1990	3.4	0.06	243
Coleman 1981	3.6		73
Hawai'ian Coots			
Present Study	4.8	0.24	69
Chang 1990	4.9	0.31	138
Byrd and Zeillemaker 1981	4.9		33

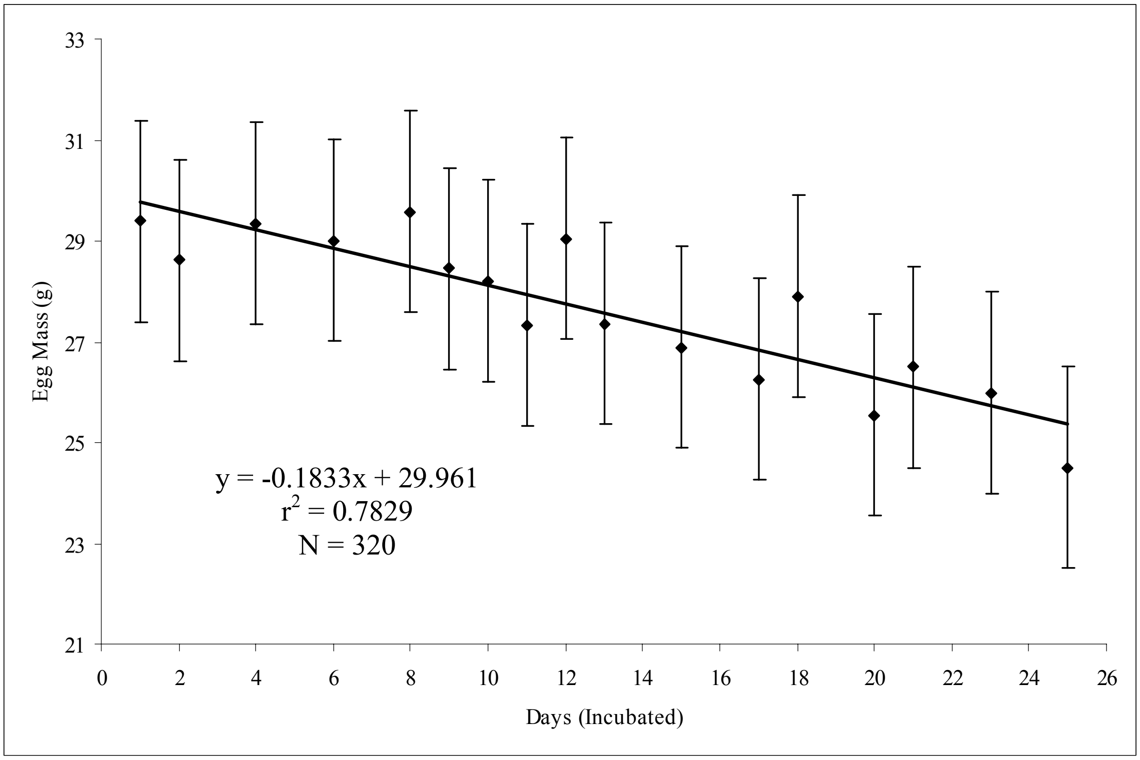

Figure 5-3. Mean egg mass for Hawai'ian coots during incubation. Linear regression explained 78% of the variability of the mean values. Mass varied daily depending upon factors influencing the microclimate at the nest and conductance of water through the eggshell.

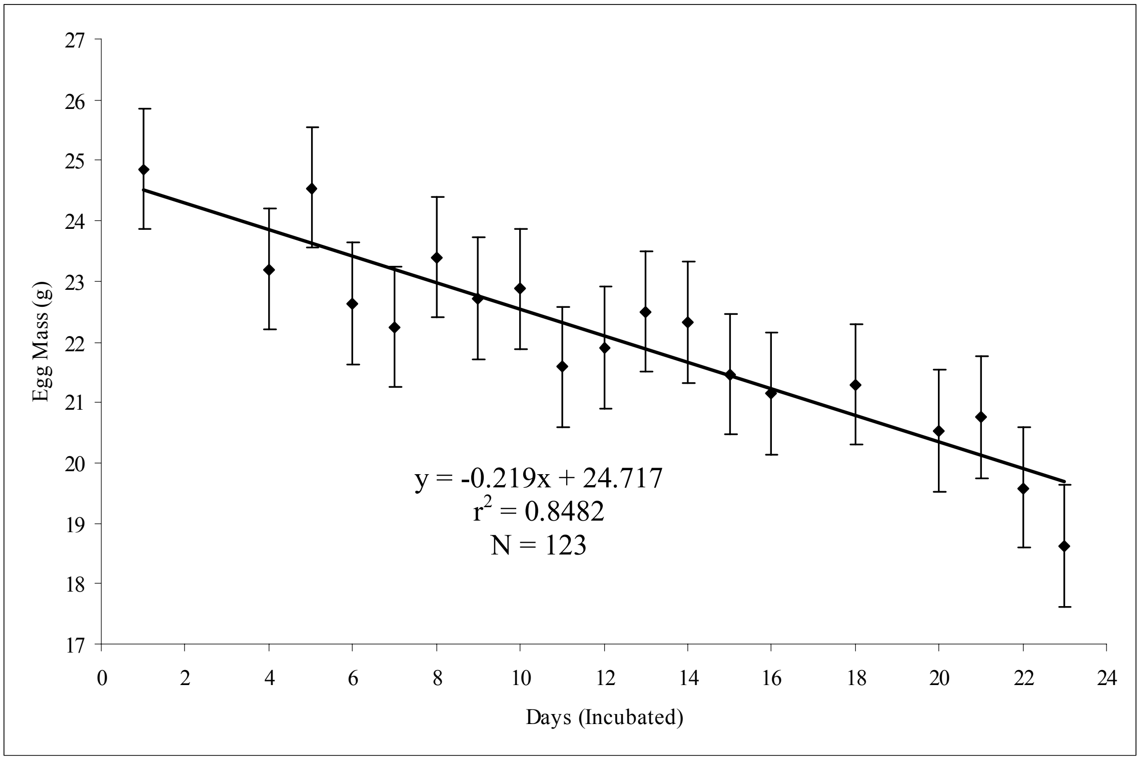

Figure 5-4. Mean egg mass for Hawai'ian stilts during incubation. Linear regression explained 85% of the variability of the mean values. Mass varied daily depending upon factors influencing the microclimate at the nest and conductance of water through the eggshell.

Table 5-3. Number of Hawai'ian stilt (HS) and Hawai'ian coot (HC) eggs laid and the number and percentage of eggs lost to predation, flooding, abandonment, and infertility on the north shore of Kealia Pond National Wildlife Refuge, Hawai'i, in 2004.

Species	N	Eggs hatched	Eggs lost	Predator	Eggs flooded	Eggs abandoned	Infertile
HS	123	69	54	22	30	0	2
		0.56	0.44	0.41	0.56	0.00	0.04
HC	320	170	150	6	70	57	17
		0.53	0.47	0.04	0.47	0.38	0.11

Table 5-4. Number of Hawai'ian stilt (HS) and Hawai'ian coot (HC) nests and the number and percentage of nests lost to predation, flooding, abandonment, and infertility on the north shore of Kealia Pond National Wildlife Refuge, Hawai'i, in 2004.

Species	N	Nest successful	Failed nest	Predator	Nest flooded	Nest abandoned	Infertile
HS	32	18	14	6	8	0	0
		0.56	0.44	0.43	0.57	0.00	0.00
HC	67	41	26	0	15	10	1
		0.61	0.39	0.00	0.58	0.38	0.04

Table 5-5. Comparison of Hawai'ian coot nesting material utilized as a percentage of total nests monitored at Kealia Pond National Wildlife Refuge from 1996-2001 and 2004.

Nest Material	1996 (N = 19)	1997 (N = 182)	1998 (N = 12)	1999 (N = 151)	2000 (N = 58)	2001 (N = 63)	2004 (N = 69)
Makai sedge	84.2	91.2	91.7	86.1	79.3	85.1	97.1
California bulrush	10.5	6.0	8.3	9.9	6.9	3.2	0.0
Pickleweed	0.0	0.0	0.0	1.3	12.1	1.6	2.9

Source: 1996- 2001 data Nishimoto (2003)

Table 5-6. Comparison of Hawai'ian coot nesting habitat as a percentage of total nests monitored at Kealia Pond National Wildlife Refuge from 1996-2001 and 2004.

Vegetation Type	1996 (N = 19)	1997 (N = 182)	1998 (N = 12)	1999 (N = 151)	2000 (N = 58)	2001 (N = 63)	2004 (N = 69)
Makai sedge	47.4	65.9	58.3	45.7	60.3	55.6	97.1
Pickleweed	15.8	16.5	0.0	17.2	19.0	23.8	2.9
California bulrush	15.8	7.7	8.3	7.9	5.2	7.9	0.0
Sedge & Pickleweed	15.8	4.3	33.3	11.3	5.2	11.1	0.0

Source: 1996- 2001 data Nishimoto (2003)

Table 5-7. Comparison of Hawai'ian coot nest success as a percentage of total nests monitored at Kealia Pond National Wildlife Refuge from 1996-2001 and 2004.

Year	Apparent nest success (N)	Nest success by Mayfield method (N)	Source
1996	90.9 (11)	86.3 (11)	Nishimoto 1999a
1997	66.3 (182)	57.4 (175)	Nishimoto 1999b
1998	83.3 (12)	77.4 (12)	Nishimoto 2000
1999	91.9 (148)	87.5 (138)	Nishimoto 2001
2000	86.2 (58)	87.3 (56)	Nishimoto 2002
2001	88.7 (62)	75.2 (44)	Nishimoto 2003
2004	61.2 (67)	35.6 (41)	Present study

Table 5-8. Comparison of Hawai'ian coot nest losses as a percentage of total nests monitored at Kealia Pond National Wildlife Refuge from 1996-2001 and 2004.

Year (N)	Flooded / drowned	Predator	Infertile / addled	Dead embryo	Abandonded	Source
1996 (11)	9.1	0.0	0.0	0.0	0.0	Nishimoto 1999a
1997 (182)	19.8	13.7	0.5	1.1	0.0	Nishimoto 1999b
1998 (12)	0.0	16.7	0.0	0.0	0.0	Nishimoto 2000
1999 (148)	4.1	4.1	0.0	0.0	0.0	Nishimoto 2001
2000 (58)	3.4	10.3	0.0	0.0	0.0	Nishimoto 2002
2001 (62)	3.2	8.1	0.0	0.0	0.0	Nishimoto 2003
2004 (67)	22.4	0.0	1.5	0.0	14.9	Present Study

Table 5-9. Comparison of Hawai'ian stilt nesting material utilized as a percentage of total nests monitored at Kealia Pond National Wildlife Refuge from 1996-2001 and 2004.

Nest material	1996 (N = 87)	1997 (N = 51)	1998 (N = 28)	1999 (N = 43)	2000 (N = 91)	2001 (N = 53)	2004 (N = 32)
Pickleweed	37.9	82.4	39.3	88.4	53.8	54.7	96.9
Makai sedge	28.7	0.0	3.6	0.0	3.2	28.3	0.0
Absent	19.5	5.9	35.7	7.0	13.2	11.3	3.1

Source: 1996- 2001 data Nishimoto (2003)

Table 5-10. Comparison of Hawai'ian stilt nesting habitat as a percentage of total nests monitored at Kealia Pond National Wildlife Refuge from 1996-2001 and 2004.

Vegetation type	1996 (N = 88)	1997 (N = 51)	1998 (N = 28)	1999 (N = 43)	2000 (N = 91)	2001 (N = 53)	2004 (N = 32)
Live pickleweed	26.1	72.5	10.7	74.4	52.7	35.8	87.5
Dead pickleweed	11.4	7.8	10.7	9.3	4.4	3.8	0.0
Makai sedge	27.3	0.0	7.1	0.0	3.2	18.9	0.0
Bare ground	19.3	5.9	53.6	7.0	23.1	22.6	6.3
Nest platform	0.0	5.9	14.3	2.3	0.0	0.0	0.0
Sprangletop	0.0	0.0	0.0	0.0	0.0	0.0	6.3

Source: 1996- 2001 data Nishimoto (2003)

Table 5-11. Comparison of Hawai'ian stilt nest success as a percentage of total nests monitored at Kealia Pond National Wildlife Refuge from 1996-2001 and 2004.

Year	Apparent nest success (N)	Nest success by Mayfield method (N)	Source
1996	43.4 (83)	42.5 (70)	Nishimoto 1999a
1997	66.0 (50)	59.4 (45)	Nishimoto 1999b
1998	61.5 (26)	55.7 (16)	Nishimoto 2000
1999	65.9 (41)	67.5 (35)	Nishimoto 2001
2000	57.1 (91)	60.5 (74)	Nishimoto 2002
2001	69.8 (53)	68.1 (51)	Nishimoto 2003
2004	56.3 (32)	37.7 (18)	Present Study

Table 5-12. Comparison of Hawai'ian stilt nest losses as a percentage of total nests monitored at Kealia Pond National Wildlife Refuge from 1996-2001 and 2004.

Year (N)	Flooded / drowned	Predator	Infertile / addled	Dead embryo	Abandonded	Source
1996 (83)	0.0	41.0	15.7	0.0	0.0	Nishimoto 1999a
1997 (50)	14.0	16.0	4.0	0.0	0.0	Nishimoto 1999b
1998 (26)	0.0	15.4	23.1	0.0	0.0	Nishimoto 2000
1999 (41)	0.0	19.5	14.6	0.0	0.0	Nishimoto 2001
2000 (91)	4.4	20.9	15.4	2.2	0.0	Nishimoto 2002
2001 (53)	0.0	26.4	3.8	0.0	0.0	Nishimoto 2003
2004 (32)	25.0	18.8	0.0	0.0	0.0	Present Study

Plant Regeneration Characteristics and Waterbird Response – Results and Discussion:

Plant Regeneration Characteristics

In 2004, information was collected on plant response and invasive plant characteristics within vegetation treatments. Only one treatment had enough vegetation response to determine the growth characteristics of plants that were present the summer after the treatments. These data reflect the response of plants 10 months after treatment and about 6 months after the sites were inundated. The sites were dry after treatment until surface flooding began about mid-November 2003. Because of wet conditions during 2004, exposed mudflats that allowed plant response were not present at the upper elevations within treatments until May 2004. Thus these data reflect the response within approximately 40 days of a drawdown. The first quadrats were randomly selected by sampling teams by throwing a meter stick over an investigators shoulder from a randomly selected site. Once data taken from this site, the next randomly selected site was determine with a similar methodology. Quadrats (N = 29) were randomly selected and stem counts of all species were recorded to determine the response of native and invasive vegetation (Table 6-1). Quadrats were dominated by sprangletop with a mean stem count of 49.80/0.5 m^2 (SD = 68.54). Pickleweed was represented with a mean stem count of 31.00/0.5 m^2 (SD = 34.65). Makai and indian marsh fleabane had the lowest mean stem counts of 17.66/0.5 m^2 (SD = 27.95) and 9.72/0.5 m^2 (SD = 16.78) respectively.

The most common invasive species present in the quadrats after treatments were pickleweed and indian marsh fleabane. The growth type, plant height or stolon length, root diameter, root length, number of shoots, and shoot length were indicators of how these invasive plants responded to treatments. Indian marsh fleabane (N = 248) regenerated solely from seed. Mean plant height was 24.8 cm (SD = 8.4). Mean root diameter and root length were 13.1 cm (SD = 6.3) and 15.1 cm (SD = 4.8) respectively. Lateral shoots (N = 109) were detected on 64 plants. Mean shoot length was 20.1 cm (SD = 9.8).

Pickleweed regenerated from seed (N = 520) and residual plant material or propagues (N = 58). Mean plant height from seed was 20.2 cm (SD = 9.1). Mean stolon length for pickleweed from residual growth was 49.1 cm (SD = 40.0). Mean root diameter and root length were 10.6 cm (SD = 8.2) and 11.3 cm (SD = 3.7) respectively for growth from seed. Conversely, mean root diameter (N = 17) and root length (N = 19) were 15.2 cm (SD = 11.8) and 17.3 cm (SD = 8.0) respectively for growth from residual plant material. Both growth forms of pickleweed exhibited lateral shoots. Lateral shoots of pickleweed from seed (N = 290) were detected on 194 plants. Mean shoot length was 13.9 cm (SD = 8.3). Lateral shoots of pickleweed from propagues (N = 333) were detected on 36 plants. Mean shoot length was 16.1 cm (SD = 25.6).

A multivariate ANOVA was utilized to determine differences in means of plant height, root diameter, root length, and number of shoots for pickleweed regenerating from seed and residual growth. Plant height ($p < 0.00$, $F = 154.89$), root diameter ($p < 0.00$, $F = 562.41$), and root length ($p < 0.00$, $F = 1181.017$) were all significantly different between the two growth types at the 95% confidence level.

Waterbird Use

Bimonthly surveys were used to detect differences in waterbird use of the refuge and study area. Prior to vegetation manipulations, vegetation height and density restricted bird use on the north shore of Kealia Pond to the areas between the dense vegetation and on the fringe of water as pond levels declined. As water levels increase above 80.00 cm at the outlet, water floods vegetation and areas available for waterbird nesting and foraging on the north shore become limited. Differences in waterbird utilization on the refuge within treated areas were detected between years. No nests were found before vegetation manipulations at the site of treatment, however 12 Hawai'ian coot nests and 29 Hawai'ian stilt nests were found on treated sites. Coot nests increased in response to the establishment of makai sedge. Stilt nests increased substantially on mudflat habitats created by roto-tilling.

Hawai'ian coot and stilt numbers increased in treated sites on Kealia Pond National Wildlife Refuge. As water levels increased between 20 November and 5 December 2003 the treated area was inundated and a substantial percentage of all birds utilizing the refuge were found in the manipulated areas (Figs. 6-1 & 6-2). This trend continued throughout the winter of 2003 and the spring and summer of 2004.

Coot and Stilt Habitat Use

Because visual surveys were used to detect Hawai'ian coots and stilts, actual water depths could not be determined. Nevertheless, water depths were recorded from shallowest to deepest using the following criteria; dry mud, wet mud, mud/water interface, foot, foot to tarsus, joint, joint to body, body, and swimming. Information on coots and stilts were recorded in all treatments, controls, and four pre-determined sites of high historic bird use (South Pond, North Ponds, Intermediate Pond, and Outlet). Water depths were estimated during the three seasons and at all locations by depth of water in comparison to tarsus length of the endangered birds. In the fall of 2003, the largest proportions of coots were detected at the outlet and in the north ponds. Approximately 94% of all Hawai'ian coots detected in the north ponds were in water depths that required swimming. Similarly, 46% of all coots detected at the outlet were in water depths that required swimming. A total of 18% utilized the mud/water interface, and 12% at body depth (Table 6-2). Stilts were detected in highest numbers in clumped and unclumped treated sites. Stilts using unclumped treatments were in joint to body and joint depths 42% and 36% of the time respectively. On clumped treatment sites, stilts utilizing joint to body depths 21% of the time and joint depths 53% of the time (Table 6-3).

In the spring of 2004, the largest numbers of coots were observed in the north ponds, clumped treatments, and unclumped treatments. Approximately 98% of all coots detected in the spring of 2004 were in habitats which required swimming. Stilts were detected in largest numbers in treated areas where they utilized a broad range of habitat. The highest numbers of stilts used water depths at foot to tarsus depths in clumped and unclumped treated areas 75% and 60% of the times respectively.

During summer 2004 maximum bird utilization continued within clumped and unclumped treatments. Hawai'ian coots were detected swimming 100% of the time within both clumped and unclumped treatments. Stilts utilized water depths from their foot to tarsus 48% of the time on clumped treatments and 45% of the time on unclumped treatments followed by a foot depth in these areas 20% and 32% of the time respectively.

Hawai'ian coot and stilt behaviors were classified into 5 broad behavior categories: feeding, sleeping/loafing, flushed, locomotion other than flying, and other, a classification composed of general maintenance activities. Approximately 58% of coots detected in the north ponds in the fall of 2003 were feeding (Table 6-4). A large portion of coots (approximately 21%) were moving around in this area an indication of feeding activity. Concurrently, large portions of stilts utilizing the treated areas were detected feeding. Foraging stilts were concentrated in treated sites where 86% used clumped treatments and 73% used unclumped treatments (Table 6-5). Of the remaining stilts in this area, 13% and 12% were detected sleeping during the time of the survey.

Hawai'ian coot behavior was monitored during spring 2004. Locomotion accounted for 63% and 58% of the time in clumped and unclumped treatments respectively. Feeding also was an important activity in these areas with foraging occurring 36% of the time in clumped treatments and 28% in unclumped treatments. The largest portions of coots in areas of historic bird use on the refuge were in the north ponds, where 55% of coots were feeding and 30% were in locomotion. During spring, stilts were concentrated in treated sites where 86% of stilts using clumped treatments and 83% using unclumped treatments were feeding.

Behavior for coots and stilts were similar between spring and summer 2004. Coots in clumped treatments were in locomotion 59% of the time and feeding 27% of the time. Coots utilizing unclumped treatments were in locomotion 64% of the time and feeding 32% of the time. Hawai'ian stilts concentrated their activity in treated areas during summer 2004. Stilts in clumped treatments were feeding 82% of the time and in locomotion 13% of the time. Stilts utilizing unclumped treatments were feeding 85% of the time and in locomotion 7% of the time.

Habitat types used by Hawai'ian coots and stilts were grouped into 8 different categories: dry mud, wet mud, mud/water interface, open water, residual vegetation (short dead pickleweed), robust emergent (live stands of pickleweed), other emergent (live or dead sprangletop or makai stands), and artificial structure. Hawai'ian coots were most commonly associated with open water, residual vegetation, robust emergent vegetation, and other emergent vegetation habitat types in all three seasons regardless of location (Table 6-6). Coots seldom or never used the dry mud, wet mud, mud/water interface, or artificial structure.

Ordinarily, Hawai'ian stilts were associated with the open water or residual vegetation. Open water habitats were extensively utilized by stilts through all three seasons. Dry mud, wet mud, mud/water interface, residual vegetation, robust emergent and emergent habitats all were moderately used by Hawai'ian stilts during the 2003 and 2004 field seasons. Hawai'ian stilts were not observed utilizing artificial structures (Table 6-7).

Table 6-1. Stem counts of species encountered and mean stem counts per quadrat on Kealia Pond National Wildlife Refuge in 2004.

Species	Total stems	Quadrat size (m^2)	# of quadrats	Mean stems $^+/_-$ SD
Batis maritima	899	0.5	29	31.00 $^+/_-$ 34.65
Leptochloa uninerviai	1444	0.5	29	49.79 $^+/_-$ 68.54
Makai sedge	512	0.5	29	17.66 $^+/_-$ 27.95
Pluchea indica	282	0.5	29	9.72 $^+/_-$ 16.78

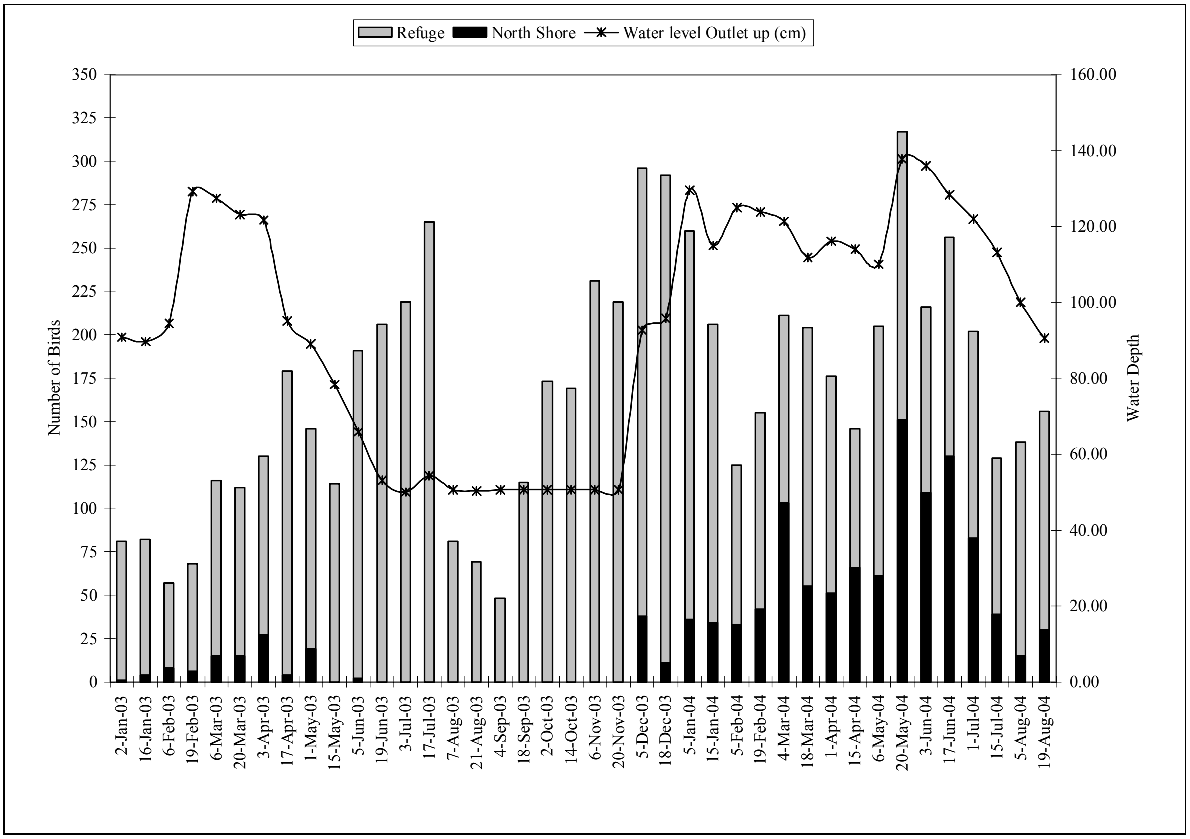

Figure 6-1. Bimonthly survey of Hawai'ian coots at Kealia Pond National Wildlife Refuge. Comparison of numbers on the refuge and numbers on the north shore within treated areas and 4 selected sites of historic bird use of Kealia Pond in relation to water levels.

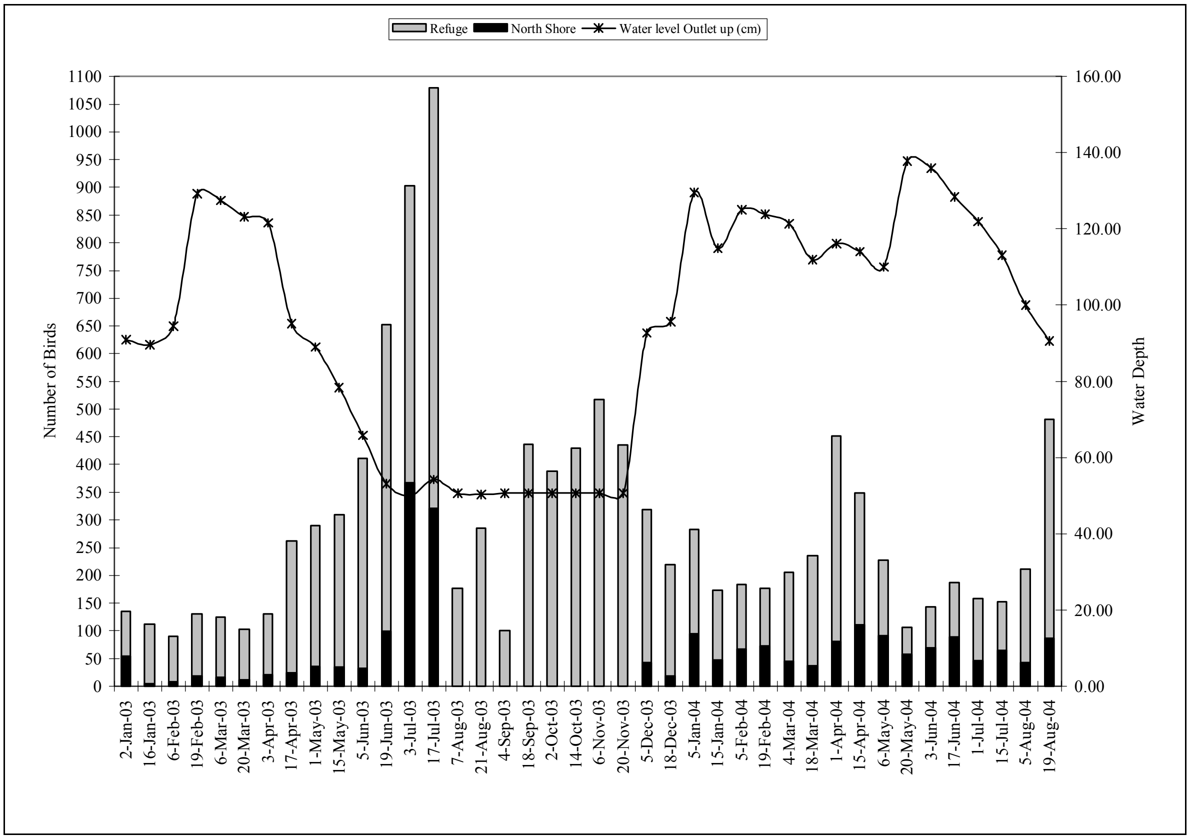

Figure 6-2. Bimonthly survey of Hawai'ian stilts at Kealia Pond National Wildlife Refuge. Comparison of numbers on the refuge and numbers on the north shore within treated areas and 4 selected sites of historic bird use of Kealia Pond in relation to water levels.

Table 6-2. Percent use of different water depths by Hawai'ian coots during visual surveys in fall of 2003 and spring and summer of 2004 in clumped, unclumped, control, and 4 selected areas of high historic bird use of Kealia Pond National Wildlife Refuge. DM = dry mud, WM = wet mud, MI = mud/water interface, FT = foot, F-T = foot to tarsus, JT = joint, JB = joint to body, BD = body, and SW = swimming.

Site	N	DM	WM	MI	OW	RV	RE	OE	AS
Fall 2003									
South pond	11	-	-	-	0.36	-	-	0.64	-
Intermediate pond	15	-	-	-	1.00	-	-	-	-
North pond	143	-	-	-	1.00	-	-	-	-
Outlet	52	0.04	0.04	0.31	0.50	0.12	-	-	-
Controls	0	-	-	-	-	-	-	-	-
Clumped treatments	9	-	-	-	1.00	-	-	-	-
Unclumped treatments	6	-	-	-	0.83	-	0.17	-	-
Spring 2004									
South pond	38	-	-		0.74	0.03	-	0.24	-
Intermediate pond	57	-	-	-	0.79	0.14	-	0.07	-
North pond	181	-	-	-	0.92	-	0.01	0.08	-
Outlet	13	-	-	-	1.00	-	-	-	-
Controls	2	-	-	-	-	-	1.00	-	-
Clumped treatments	185	-	-	-	0.89	0.09	0.01	0.01	-
Unclumped treatments	215	-	-	-	0.84	0.08	0.05	0.04	-
Summer 2004									
South pond	9	-	-		1.00	-	-	-	-
Intermediate pond	10	-	-	-	1.00	-	-	-	-
North pond	81	-	-	-	1.00	-	-	-	-
Outlet	5	-	-	-	1.00	-	-	-	-
Controls	0	-	-	-	-	-	-	-	-
Clumped treatments	512	-	-	-	0.48	0.42	0.06	0.04	-
Unclumped treatments	665	-	-	-	0.80	0.13	-	0.07	-

Table 6-3. Percent use of different water depths by Hawai'ian stilts during visual surveys in fall of 2003 and spring and summer of 2004 in clumped, unclumped, control, and 4 selected areas of high historic bird use of Kealia Pond National Wildlife Refuge. DM = dry mud, WM = wet mud, MI = mud/water interface, FT = foot, F-T = foot to tarsus, JT = joint, JB = joint to body, BD = body, and SW = swimming

Site	N	DM	WM	MI	FT	F-T	JT	JB	BD	SW
Fall 2003										
South pond	0	-	-	-	-	-	-	-	-	-
Intermediate pond	29	-	-	-	-	0.10	0.24	0.31	0.34	-
North pond	5	-	-	-	-	0.40	0.40	0.20	-	-
Outlet	18	0.06	-	0.17	0.11	0.50	0.11	0.06	-	-
Controls	0	-	-	-	-	-	-	-	-	-
Clumped treatments	47	-	-	-	0.11	0.15	0.53	0.21	-	-
Unclumped treatments	92	-	-	-	0.08	0.10	0.36	0.42	0.04	-
Spring 2004										
South pond	15	-	-	-	-	0.80	0.20	-	-	-
Intermediate pond	34	-	-	-	-	0.44	0.35	0.21	-	-
North pond	8	-	-	-	-	-	1.00	-	-	-
Outlet	0	-	-	-	-	-	-	-	-	-
Controls	1	-	-	-	-	1.00	-	-	-	-
Clumped treatments	383	0.01	0.05	0.03	0.07	0.75	0.08	0.01	0.01	-
Unclumped treatments	311	-	0.07	0.07	0.07	0.60	0.13	0.04	0.03	-
Summer 2004										
South pond	32	-	-	-	0.09	0.78	0.13	-	-	-
Intermediate pond	2	-	-	-	-	1.00	-	-	-	-
North pond	2	-	1.00	-	-	-	-	-	-	-
Outlet	0	-	-	-	-	-	-	-	-	-
Controls	0	-	-	-	-	-	-	-	-	-
Clumped treatments	548	0.03	0.10	0.10	0.20	0.48	0.04	0.05	-	-
Unclumped treatments	414	0.04	0.06	0.05	0.32	0.45	0.06	0.01	0.01	-

Table 6-4. Behaviors exhibited by Hawai'ian coots during visual surveys in fall of 2003 and spring and summer of 2004 in clumped, unclumped, control, and 4 selected areas of high historic bird use of Kealia Pond National Wildlife Refuge. FE = feeding, SL = sleeping, FL = flushed, LM = locomotion (swimming/walking), FY = flying, and OT = other (maintenance).

Site	N	FE	SL	FL	LM	FY	OT
Fall 2003							
South pond	11	0.09	-	-	0.18	-	0.73
Intermediate pond	15	0.47	0.20	-	0.20	-	0.13
North pond	143	0.58	0.16	0.01	0.21	-	0.03
Outlet	52	0.40	0.12	0.06	0.31	-	0.12
Controls	0	-	-	-	-	-	-
Clumped treatments	9	0.56	-	-	0.44	-	-
Unclumped treatments	6	0.33	-	-	0.67	-	-
Spring 2004							
South pond	38	0.34	0.21	0.11	0.34	-	-
Intermediate pond	57	0.37	-	-	0.60	-	0.04
North pond	181	0.55	0.07	-	0.30	-	0.08
Outlet	13	0.15	-	-	0.85	-	-
Controls	2	-	-	-	-	-	1.00
Clumped treatments	185	0.36	-	0.01	0.63	-	-
Unclumped treatments	215	0.28	0.07	0.06	0.58	-	0.01
Summer 2004							
South pond	9	0.11	-	-	0.89	-	-
Intermediate pond	10	0.30	-	-	0.70	-	-
North pond	81	0.17	-	-	0.77	0.06	-
Outlet	5	-	-	-	1.00	-	-
Controls	0	-	-	-	-	-	-
Clumped treatments	512	0.27	-	0.14	0.59	-	-
Unclumped treatments	665	0.32	-	0.04	0.64	-	-

Table 6-5. Behaviors exhibited by Hawai'ian stilts during visual surveys in fall of 2003 and spring and summer of 2004 in clumped, unclumped, control, and 4 selected areas of high historic bird use of Kealia Pond National Wildlife Refuge. FE = feeding, SL = sleeping, FL = flushed, LM = locomotion (swimming/walking), FY = flying, and OT = other (maintenance).

Site	N	FE	SL	FL	LM	FY	OT
Fall 2003							
South pond	4	-	-	1.00	-	-	-
Intermediate pond	29	0.93	-	-	-	-	0.07
North pond	11	0.09	0.18	0.73	-	-	-
Outlet	18	0.67	0.28	-	-	-	0.06
Controls	1	-	-	1.00	-	-	-
Clumped treatments	48	0.73	0.13	0.02	0.02	-	0.10
Unclumped treatments	92	0.85	0.12	0.03	-	-	-
Spring 2004							
South pond	20	0.70	-	0.30	-	-	-
Intermediate pond	33	0.97	-	0.03	-	-	-
North pond	9	0.89	-	0.11	-	-	-
Outlet	0	-	-	-	-	-	-
Controls	1	-	-	-	-	-	1.00
Clumped treatments	396	0.86	0.02	0.02	0.07	0.03	0.02
Unclumped treatments	311	0.83	0.02	0.11	0.01	-	0.04
Summer 2004							
South pond	36	0.61	-	0.11	0.14	0.06	0.08
Intermediate pond	2	1.00	-	-	-	-	-
North pond	2	-	-	-	1.00	-	-
Outlet	0	-	-	-	-	-	-
Controls	0	-	-	-	-	-	-
Clumped treatments	550	0.82	0.02	0.01	0.13	-	0.01
Unclumped treatments	415	0.85	0.05	0.01	0.07	-	0.02

Table 6-6. Percent use of different habitat types by Hawai'ian coots during visual surveys in fall of 2003 and spring and summer of 2004 in clumped, unclumped, control, and 4 selected areas of high historic bird use of Kealia Pond National Wildlife Refuge. DM = dry mud, WM = wet mud, MI = mud/water interface, OW = open water, RV = residual vegetation (dead pickleweed), RE = robust emergent (live pickleweed) OE = other emergent (Makai sedge and Sprangletop), and AS = artifical structure.

Site	N	DM	WM	MI	OW	RV	RE	OE	AS
Fall 2003									
South pond	11	-	-	-	0.36	-	-	0.64	-
Intermediate pond	15	-	-	-	1.00	-	-	-	-
North pond	143	-	-	-	1.00	-	-	-	-
Outlet	52	0.04	0.04	0.31	0.50	0.12	-	-	-
Controls	0	-	-	-	-	-	-	-	-
Clumped treatments	9	-	-	-	1.00	-	-	-	-
Unclumped treatments	6	-	-	-	0.83	-	0.17	-	-
Spring 2004									
South pond	38	-	-		0.74	0.03	-	0.24	-
Intermediate pond	57	-	-	-	0.79	0.14	-	0.07	-
North pond	181	-	-	-	0.92	-	0.01	0.08	-
Outlet	13	-	-	-	1.00	-	-	-	-
Controls	2	-	-	-	-	-	1.00	-	-
Clumped treatments	185	-	-	-	0.89	0.09	0.01	0.01	-
Unclumped treatments	215	-	-	-	0.84	0.08	0.05	0.04	-
Summer 2004									
South pond	9	-	-		1.00	-	-	-	-
Intermediate pond	10	-	-	-	1.00	-	-	-	-
North pond	81	-	-	-	1.00	-	-	-	-
Outlet	5	-	-	-	1.00	-	-	-	-
Controls	0	-	-	-	-	-	-	-	-
Clumped treatments	512	-	-	-	0.48	0.42	0.06	0.04	-
Unclumped treatments	665	-	-	-	0.80	0.13	-	0.07	-

Table 6-7. Percent use of different habitat types by Hawai'ian stilts during visual surveys in fall of 2003 and spring and summer of 2004 in clumped, unclumped, control, and 4 selected areas of high historic bird use of Kealia Pond National Wildlife Refuge. DM = dry mud, WM = wet mud, MI = mud/water interface, OW = open water, RV = residual vegetation (dead pickleweed), RE = robust emergent (live pickleweed) OE = other emergent (Makai sedge and Sprangletop), and AS = artifical structure.

Site	N	DM	WM	MI	OW	RV	RE	OE	AS
Fall 2003									
South pond	4	-	-	-	1.00	-	-	-	-
Intermediate pond	29	-	-	-	0.79	-	0.07	0.14	-
North pond	11	-	-	-	-	-	-	1.00	-
Outlet	18	0.06	0.22	0.28	0.44	-	-	-	-
Controls	1	-	-	-	-	-	1.00	-	-
Clumped treatments	48	-	-	-	0.77	-	0.10	0.13	-
Unclumped treatments	92	-	-	-	0.75	0.03	0.01	0.21	-
Spring 2004									
South pond	20	-	-	-	0.80	0.05	-	0.15	-
Intermediate pond	33	-	-	-	0.52	-	-	0.48	-
North pond	9	-	-	-	0.56	-	0.11	0.33	-
Outlet	0	-	-	-	-	-	-	-	-
Controls	1	-	-	-	1.00	-	-	-	-
Clumped treatments	396	0.01	0.14	0.07	0.32	0.41	0.03	0.03	-
Unclumped treatments	311	-	0.17	0.07	0.44	0.18	0.10	0.04	-
Summer 2004									
South pond	36	-	0.06	-	0.67	0.14	0.06	0.08	-
Intermediate pond	2	-	-	-	1.00	-	-	-	-
North pond	2	-	-	-	-	1.00	-	-	-
Outlet	0	-	-	-	-	-	-	-	-
Controls	0	-	-	-	-	-	-	-	-
Clumped treatments	550	0.03	0.09	0.07	0.32	0.44	-	0.05	-
Unclumped treatments	415	0.01	0.07	0.23	0.36	0.30	-	0.02	-

Future Research and Management Recommendations:

Research

Further research would fill gaps in the life history strategies of these endangered waterbirds. This study identified the value of managed seasonal wetlands for Hawai'ian endangered waterbirds. Information on food type, biomass, and distribution of resources in managed areas may identify more specific attributes of prime habitats for Hawai'ian coots and stilts. Determining invertebrate and vegetation association may be the appropriate direction to answer this question.

The variation in nest construction, egg size, and clutch size has been documented in this study and from other studies in Hawai'i. Further research on the growth, development, survival, and dispersal of young Hawai'ian coots and stilts would be helpful in identifying response to management or problems associated with the successful completion of the annual cycle. Comparing egg mass loss during incubation among different geographic locations in Hawai'i may provide information concerning how different breeding populations respond to climatic and habitat variability.

The condition of Hawai'ian wetlands required to maintain populations of endangered waterbirds is unknown. Furthermore, the distribution of endangered waterbirds throughout the annual cycle within Hawai'ian wetlands is poorly understood. The Kealia refuge staff has had limited success with marking individual Hawai'ian coot and stilt chicks after fledging due to the secretive nature of these birds and the dense vegetation within the refuge. Radio tracking or use of plasticine leg bands on stilt chicks would provide further data on growth and provide insight into survival and dispersal.

Long-term radio or satellite tracking of young or adults would provide information on dispersal, philopatry, survival, as well as correlation of these movements to climatic events. Information on dispersal and survival would guide biologists and refuge managers in understanding population dynamics for Hawai'ian endangered waterbirds on a statewide scale.

Management

My management recommendations for endangered waterbirds in Hawai'i will be general and should be determined by the goals, objectives, and management capabilities. Maintaining suitable interspersion of open water and vegetation is essential in managed wetlands in Hawai'i because the long growing season and abundance of invasive plant species result in monotypic stands of vegetation that are too dense for bird use in the absence of management. I suggest the importance of identifying habitat availability at different water levels because this information has the potential to guide management for ideal conditions required by endangered waterbirds as water levels fluctuate throughout the year. Manipulating water levels and controlling undesirable vegetation in wetlands allows managers to produce desired hydrophytes, seed abundances, and stem densities that provide food and cover for waterbirds (Griffin *et al.* 1990).

The staff at Kealia Pond National Wildlife Refuge has limited ability to control water levels in the main pond. This challenge affects management options on the refuge. reas such as the small management pools adjacent to the refuge headquarters and the pools on the west side of the refuge at the old hatchery, where water level and management is possible, should be manipulated utilizing tillage equipment in combination with fluctuating water levels to create habitat conditions that maximize bird utilization. Pools within these complexes could be managed during alternate years to provide structure and water levels for both Hawai'ian coots and stilts. Dense invasive vegetation on the levees should be removed to encourage germination of low growing native plants, remove travel corridors used by predators, and permit movement of endangered waterbirds between pools.

Primary vegetation management objectives should focus on the removal and control of indian marsh fleabane and pickleweed to benefit nesting and foraging of endangered waterbirds. Indian marsh fleabane is a woody invasive that dominates the west side of the refuge and levees at the fish pond. At maturity, indian marsh fleabane removal is labor intensive and may require heavy equipment. Mature plants provide no benefit to endangered water birds and may serve as cover for predator species. Indian marsh fleabane could be removed utilizing a Bobcat or chainsaw, piled, and burned during the dry season. Once mature plants are removed, regenerating plants or residual growth can be controlled with herbicide or tillage treatments.

Pickleweed has invaded most of the area at Kealia Pond National Wildlife Refuge outside the main pool. Furthermore, pickleweed is not a food source for endangered stilts (coots probably eat the seeds) and provides little structural benefit for invertebrates. Tillage and mowing manipulations in extensive stands of pickleweed create a mosaic of vegetation and mudflat of value for Hawai'ian coots and stilts. At Kealia Pond National Wildlife Refuge, I observed that patches of pickleweed left within large expanses of mudflat capture sediments and form areas of slightly higher microtopography. After removing vegetation, these areas of higher relief are utilized by Hawai'ian stilts as nesting islands. Initial treatment intensity and frequency in these areas of dense pickleweed may be substantial, but the effort should decrease over time as other plant species become competitive with pickleweed for space and nutrients. My observation at Kealia Pond National Wildlife Refuge is that areas of frequent refuge activities, such as the trails on the north shore, are generally absent of pickleweed, are dominated by annuals, and may be maintained with an annual or semi-annual mowing treatment.

Kealia Pond National Wildlife Refuge is on the leeward side of the island of Mau'i where precipitation is limited. This condition creates a challenge in managing vegetation. Because of the seasonality of the pond, there is limited habitat available for Hawai'ian stilts and coots during the dry summer and fall. Although refuge wells are used to add water to the headquarters and main pools, to control dust and to maintain some surface flooding, these wells and their delivery system cannot deliver water to the high elevational habitats along the north shore. I suggest the addition of a well and water delivery system along the northern edge of the refuge if additional infrastructure development is considered. Such a system would enable the refuge to provide water to the main pond during times of low water levels by providing sheet flow across the north shore. Sheet flow would aid in the regeneration of desired plants and provide mudflat habitat over a larger expanse of the refuge for Hawai'ian stilts. Developing this high elevation habitat during the dry season will aid in creating the conditions required by these birds on portions of the refuge that will be inundated during the wet season and may extend the breeding season of Hawai'ian stilts observed at Kealia Pond National Wildlife Refuge.

My results in combination with past research suggest that water depth, vegetation structure, and interspersion in seasonally flooded wetlands are important for endangered Hawai'ian waterbirds. Varying water levels during the breeding season provides a reliable food source for Hawai'ian coots and stilts while creating conditions for germination of annual vegetation. Controlling robust vegetation, such as pickleweed, in proximity to emergent annual vegetation provides areas for nest construction that provide protection from trade winds and wave action. The interspersion of open water and emergent vegetation provide Hawai'ian coots and stilts with foraging and nesting habitat in close proximity. Interspersion can change rapidly depending upon the amount of precipitation and water input into the system during high water events. Because of the physical constraints of controlling water levels at Kealia Pond National Wildlife Refuge, it is necessary to monitor water levels, synthesize information, and amend management strategies to provide habitats throughout the breeding season to maximize nesting and foraging by Hawai'ian coots and stilts. By consistently providing these conditions across wet and dry cycles, population increases may occur that have the potential to result in the delisting of these endangered birds.

Literature Cited

American Ornithologists' Union. 1983. Checklist of North American Birds, 6th Ed. Lawrence, Kansas: Allen Press. 877pp.

___________. 1993. Thirty-ninth supplement of the American Ornithologists' Union Checklist of North American Birds. Auk 110:675-682.

Ashkenazi, S. and Y. Yom-Tov. 1997. The breeding biology of the black-crowned night heron (*Nycticrax nycticrax*) and the little egret (*Egretta garzetta*) at the Huleh Nature Reserve, Israel. Journal of Zoology. 242:623-641.

Banko, W. E. 1988. History of endemic Hawai'ian birds. Part I. Population histories-species accounts. Freshwater birds: Hawai'ian Stilt Aeo. CPSU/UH Avian History Rep. 12 D. University of Hawai'i, National Park Service, Honolulu HI.

Bent, A. C. 1926. Life histories of North American marsh birds. U.S. Natl. Mus. Bull. 135.

___________. 1927. Life histories of North American shorebirds. Part 1. U.S. Natl. Mus. Bull. 142.

Berger, A. J. 1967. The incubation period of the Hawai'ian Stilt. Auk 84:130.

___________. 1981. Hawai'ian birdlife. 2nd ed. University of Hawai'i Press, Honolulu.

Brown, M. and J. J. Dinsmore. 1986. Implications of marsh size and isolation for marsh bird management. Journal of Wildlife Management 50(3):392-397.

Byrd, G. V. and C. F. Zeillemaker. 1981. Ecology of nesting Hawai'ian common gallinules at Hanalei, Hawai'i. Western Birds 12:105-116.

___________., R. A. Coleman, R. J. Shallenberger, and C. S. Arume. 1985. Notes on the breeding biology of the Hawai'ian race of American coot. 'Elepaio 45:57-63

Chang, P. R. 1990. Strategies for managing endangered waterbirds on Hawai'ian National Wildlife Refuges. M.S. Thesis, University of Massachusetts.

Coleman, R. A. 1978. Coots prosper at Kakahai'a refuge. 'Elepaio 38:130.

___________. 1981. The reproductive biology of the Hawai'ian subspecies of the black-necked stilt, *Himantopus mexicanus knudseni.* Ph.D. diss., Pennsylvania State Univ. 106pp.

Cummings, L. S. 1993. Pollen and macrofloral analysis at site 50-30-03-1027, Hanalei Valley, Kaua'i Island, Hawai'i. Paleo Research Labs Technical Report 93-92, Biosystems Analysis Incorporated, Kailua, Hawai'i.

Dahl, T. E. 1990. Wetland losses in the United States 1780s to 1980s. U.S. Dept. Int., USFWS, Washington, D.C. 13pp.

Dougherty, M., M. L. Ueoka, L. T. Hirai, and T. C. Telfer. 1978. Limited study of nesting by stilts on the island of Mau'i, O'ahu, and Kaua'i. Progress Rep., Job no. R-III-C, Project no. W-18-R-2. Div. For. Wildl., Honolulu.

Engilis, A., Jr. and T. K. Pratt. 1993. Status and population trends of Hawai'i native waterbirds, 1977-1987. Wilson Bull. 105:142-158.

Fredrickson, L. H. 1977. American coot (*Fulica americana*). Pages 120-147 *in* Sanderson, G. C. ed. Management of migratory shore and upland game birds in North America. The International Association of Fish and Game Agencies, Washington, D.C.

___________. and M. K. Laubhan. 1994a. Intensive Wetland Management: A Key to Biodiversity. Pages 555-565 *in* T.A. Bookhouse, ed., Research and management techniques for wildlife and habitats in North America. Fifth Ed. The Wildlife Society, Bethesda, MD

___________. and M. K. Laubhan. 1994b. Managing wetlands for wildlife. Pages 623-647 *in* T.A. Bookhous, ed., Research and management techniques for wildlife and habitats in North America. Fifth Ed. The Wildlife Society, Bethesda, MD.

___________. and T. S. Taylor. 1982. Management of Seasonally Flooded impoundments for wildlife. Resource Publication 148. United States Fish and Wildlife Service, Washington, D.C.

___________. and F. A. Reid. 1986. Wetland and riparian habitats: A nongame management overview. Pages 59-96 *in* J.B. Hale, L.B. Best and R.L. Clawson. Eds., Management of nongame wildlife in the Midwest: A developing art. North-Cent. Sect., The Wildl. Soc., Grand Rapids, MI.

___________. and F. A. Reid. 1988. Waterfowl use in wetland complexes. U.S. Fish and Wildlife Service, Fish and Wildlife Leaflet. 13.2.1. 6pp.

___________. and F. A. Reid. 2001. Preliminary considerations for manipulating vegetation. U.S. Fish and Wildlife Service, Waterfowl Management for Wildlife Handbook. 13.4.9. 5pp.

Fredrickson, N. L. 1996. High Densities of Least Bitterns: Source or Sink. Senior Thesis. The Colorado College.

Grant, G. S. 1982. Avian incubation: egg temperature, nest humidity, and behavior thermoregulation in a hot environment. Ornithol. Monogr. 30.

Griffin, C. R. 1994. Management and habitat selection of endangered waterbirds in Hawai'i. Draft Report to USFWS. Contract: USDI 14-16-0009-1509.

___________., R. J. Shallenberger, and S. I. Fefer. 1990. Hawai'i's endangered waterbirds: a resource management challenge. Pages. 1165-1175 *in* Freshwater wetlands and wildlife (R. R. Sharitz and J. W. Gibbons, eds.) U.S. Dept. of Energy, Office of Sci. and Tech. Information, Oak Ridge, TN.

Gullion, G. W. 1954. The reproductive cycle of American Coots in California. Auk 71: 366-412.

Hamilton, R. B. 1975. Comparative behavior of the American Avocet and the Black-necked Stilt (Recurvirostridae). Ornithol. Monogr. 17.

Hands, H. M., M. R. Ryan and J. W. Smith. 1991. Migrant shorebird use of marsh, moist-soil, and flooded agricultural habitats. Wildlife Society Bulletin. 19:457-464.

Harris, S. W. and W. H. Marshall. 1957. Some effects of severe windstorm on coot nests. Journal of Wildlife Management 21:471-473.

Helmers, D. L. 1991. Habitat use by migrant shorebirds and invertebrate availability in a managed wetland complex. Thesis, University of Missouri, Columbia, MO, USA.

___________. 1993. Enhancing the Management of Wetlands for Migrant Shorebirds. Transactions North American Wildlife and Natural Resources Conferences. 58:335-344.

Henshaw, H. W. 1902. Birds of the Hawai'ian Islands, being a complete list of the Hawai'ian possessions with notes on their habits. Thos. G. Thurm, Honolulu, HI.

Hensler, G. L., and J. D. Nichols. 1981. The Mayfield method of estimating nest success: a model, estimators, and simulation results. Wilson Bull. 93:42-53.

James, R. A., Jr. 1995. Natal philopatry, site tenacity, and age of first breeding of the Black-necked Stilt. J. Field Ornithol. 66:17-111.

Juvik, S. P. and J. O. Juvik, editors. 1998. Atlas of Hawai'i. 3rd ed. University of Hawai'i Press, Honolulu, HI. USA.

Kelley, J. R., Jr. 1986. Management and biomass production of selected moist-soil plants. M.S. Thesis, University of Missouri, Columbia, MO, USA.

Keppie, D. M. 1985. Weight loss of spruce grouse eggs during incubation. Canadian Journal of Zoology 63:888-890.

Maciolek, J. 1971. Aquatic ecosystems of Kealia floodplain and Maalaea Bay, Mau'i, evaluation for perpetuation and public use. Technical Report No. 27. Hawai'i Institute of Marine Biology, University of Hawai'i.

Manning, T. H. 1982. Daily measurements of variation in weight loss of eggs of seven passerine species before and during natural incubation. Canadian Journal of Zoology. 60:3143-3149.

Martin, T. E. 1986. Competition in breeding birds: on the importance of considering processes at the level of the individual. Current Ornithology. 4:181-210.

___________. 1988. Processes organizing open-nesting bird assemblages: competition or nest predation? Evol. Ecol. 2:37-50.

___________. 1992. Breeding productivity considerations: what are the appropriate habitat features for management? Pages 455-473 *in* J.M. Hagen and D.W. Johnston, eds. Ecology and conservation of Neotropical migrant birds. Smithson. Inst. Press, Washington, D.C.

___________, and G. R. Geupel. 1993. Nest-monitoring plots: methods for locating nests and monitoring success. Journal of Field Ornithol. 64(4):507-519.

Mayfield, H. F. 1961. Nesting success calculated from exposure. Wilson Bull. 75:255-261.

___________. 1975. Suggestions for calculating nest success. Wilson Bull. 87:456-466.

Macdonald, G. A., A. T. Abbott, and F. L. Peterson. 1983. Volcanoes in the Sea: The Geology of Hawai'i. 2nd ed. University of Hawai'i Press, Honolulu.

Miller, A. W. and B. D. Collins. 1954. A nesting study of ducks and coots on the Tule Lake and Lower Klamath National Wildlife Refuges. Cal. Fish and Game 40:17-37.

Morin, M. P. 1994. Hawai'ian fishponds and endangered waterbirds on the Kona coast. Trans. West. Sect. Wildl. Soc. 30:66-71.

___________. 1998. Endangered waterbird and wetland status. Kaloko-Honokohau National Historical Park. Hawai'i Island. Cooperative National Park Resources Studies Unit. University of Hawai'i at Manoa, Tech. Rep. 119.

Morrison, R. I. G. 1991. Research Requirements for Shorebird Conservation. Transactions North American Wildlife and Natural Resources Conferences. 58:473-480.

Mortimer, D. 1890. Notes on habits of a few birds in Orange County, Florida. Auk 7:337-343.

Munro, G. C. 1944. Birds of Hawai'i. Tongg Publ. Co., Honolulu.

___________. 1960. Birds of Hawai'i. Rutland, Vermont & Tokyo: Charles E. Tuttle Co. 192pp.

Nakai, G. and T. Mayer. 2001. Soils and Sediment Summary at Kealia Pond NWR. Technical Report.

Nelson, F. A. 2003. Habitat Selection and Breeding Ecology of Least Bitterns in Northwest Missouri on Squaw Creek National Wildlife Refuge. M.S. Thesis, University of Missouri, Columbia, MO, USA.

Nishimoto, M. 1999a. Waterbirds of Kealia Pond National Wildlife Refuge during 1996. Unpublished administrative report. USFWS, Kihei, Hawai'i.

___________. 1999b. Waterbirds of Kealia Pond National Wildlife Refuge during 1997. Unpublished administrative report. USFWS, Kihei, Hawai'i.

___________. 2000. Waterbirds of Kealia Pond National Wildlife Refuge during 1998. Unpublished administrative report. USFWS, Kihei, Hawai'i.

___________. 2001. Waterbirds of Kealia Pond National Wildlife Refuge during 1999. Unpublished administrative report. USFWS, Kihei, Hawai'i.

___________. 2002. Waterbirds of Kealia Pond National Wildlife Refuge during 2000. Unpublished administrative report. USFWS, Kihei, Hawai'i.

___________. 2003. Waterbirds of Kealia Pond National Wildlife Refuge during 2001. Unpublished administrative report. USFWS, Kihei, Hawai'i.

Ohashi, T. J., and T. C. Telfer. 1977. Limited study of nesting by stilts on the island of Mau'i, O'ahu, and Kaua'i. Progress Rep., Job no. R-III-C, Project no. W-18-R-2. Div. For. Wildl., Honolulu.

Olson, S. L. and H. F. James. 1991. Descriptions of thirty-two new species of birds from the Hawai'ian Islands: Part I. Non-passeriforms. Ornith. Monogr. 45:1-88.

Paton, P. W. C., J. M. Scott, and T. A. Burr. 1985 American Coot and Black-necked Stilt in the island of Hawai'i. Western Birds 16:175-181.

Perkins, R. C. L. 1903. Vertebrata. Pages 365-466 *in* Fauna Hawai'iensis or the zoology of the Sandwich (Hawai'ian) Isles. Vol. 1, Pt. IV (D. Sharp, ed.). University Press, Cambridge, U.K.

Pratt, H.D. 1987. Occurrence of the North American coot (*Fulica americana americana*) in the Hawai'ian Islands, with comments on the taxonomy of the Hawai'ian coot. 'Elepaio 47:24-28

__________. and I. L. Brisbin JR. 2002. Hawai'ian Coot (*Fulica alai*). *The Birds of North America, No. 697*. (A. Poole and F. Gill, editors). The Birds of North America, Inc., Philadelphia, PA.

Pyle, R. L. 1994. Hawai'ian Islands region. Natl. Audubon Soc. Field Notes 48:343-344.

Rahn, H. and A. Ar. 1974. The avian egg: Incubation time and water loss. The Condor. 76:147-152.

Reed, J. M. and L. W. Oring. 1993. Long-term population trends of the endangered Ae'o (Hawai'ian stilt, *Himantopus mexicanus knudseni*). Trans. Western Sec. Wildl. Soc. 30:7-14.

Robel, R. J., J. N. Briggs, A. D. Dayton and L. C. Hulbert. 1970. Relationships between visual obstructions measurements and weight of grassland vegetation. Journal of Range Management 23:296-297.

Robinson, J. A., J. M. Reed, J. P. Skorupa, and L. W. Oring. 1999. Black-necked Stilt (*Himantopus mexicanus*). *The Birds of North America, No. 449*. (A. Poole and F. Gill, editors). The Birds of North America, Inc., Philadelphia, PA.

Rundle, W. D. and L. H. Fredrickson. 1981. Managing seasonally flooded impoundments for migrant rails and shorebirds. Wildlife Society Bulletin 9:80-87.

Ryder, R. A. 1961. Coot and duck productivity in northern Utah. Twenty-sixth North American Wildlife Conference 26:124-147.

Saunders, D. A. and G. T. Smith. 1981. Egg dimensions and egg weight loss during incubation in five species of cockatoo, and the use of measurements to determine the stage of incubation of bird's eggs. Australian Wildlife Research 8:411-419.

Schwartz, C. W. and E. R. Schwartz. 1949. The game birds in Hawai'i. Div. Fish & Game and Board Comm. Agric. & For., Honolulu. 168pp.

Schwartz, C. W. and E. R. Schwartz. 1952. The Hawai'ian Coot. Auk 69:446-449.

Senner, S. E. and M. A. Howe. 1984. Conservation of nearctic shorebirds. Pages 379-421 *in* J. Burger and B.L. Olla, eds., Shorebirds: Breeding behavior and populations. Plenum Press, New York, NY.

Shallenberger, R. J. 1977. An ornithological survey of the Hawai'ian wetlands. Contract DACW 84-77-C-0036, U.S. Army Eng. Dist., Honolulu. Ahuimanu Productions. 406pp.

Sooter, C. A. 1941. Ecology and management of the American Coot, *Fulica americana americana* Gmelin. Ph.D. diss., Iowa State University, Ames.

Sordahl, T. A. 1996. Breeding biology of the American Avocet and Black-necked Stilt in northern Utah. Southwest. Nat. 41:348-354.

State Dept. of Land and Natural Resources Water Bird Surveys. 1983 to 1996. Waterbird Survey Records. Unpublished data on file at State Department of Land and Natural Resources, Honolulu, HI.

Stemmermann, L. 1981. A guide to Pacific wetland plants. United States Army Corps of Engineers. Honolulu District, Honolulu, Hawai'i.

Sugden, L. G. 1979. Habitat use by nesting American coots in Saskatchewan parklands. Wilson Bulletin 91:599-607.

Telfer, T. C. 1973. Field investigations of native Hawai'ian waterbirds on the island of Kaua'i (S.I.). Progress Rep., Job no. VIII-C(3), Project no. W-15-3. Div. For. Wildl., Honolulu.

Tomich, P. Q. 1969. Mammals in Hawai'i. Bernice P. Bishop Museum Special Publication 57. Honolulu: Bishop Museum Press. 238pp.

Udvardy, M. D. F. 1960. Movements and concentrations of the Hawai'ian coot on the Island of O'ahu. 'Elepaio 21:20-22.

Ueoka, M. L., J. S. Dalrymple, and T. C. Telfer. 1976. Limited study of nesting by stilt on the islands of Mau'i, O'ahu, and Kaua'i. Progress Rep., Job no. R-III-C, Project no. W-18-R-1. Div. For. Wildl., Honolulu.

U.S. Census Bureau. 2003. Mau'i County Census Data. <http://quickfacts.census.gov/qfd/states/15/15009.html> (22 April 2003).

U.S. Fish and Wildlife Service. 1970. Conservation of Endangered Species and other Fish or Wildlife: United States List of Endangered Native Fish and Wildlife. Federal Register 35(199):16047-16048.

___________. 1983. Master Plan – Hawai'ian wetland National Wildlife Refuge Complex (Draft). 2 volumes.

___________. 1990. Amendment letter on Hawai'ian wetland status to Dahl 1990, Honolulu.

___________. 1995. Kealia Pond National Wildlife Refuge (brochure). United States Department of Interior, Washington, D.C., USA.

___________. 1998. Technical agency draft revised recovery plan for Hawai'ian waterbirds. Third revision United States Fish and Wildlife Service, Portland, Oregon.

___________. 1999a. Draft Revised Recovery Plan for Hawai'ian Waterbirds. Second Revision. United States Fish and Wildlife Service, Portland, Oregon.

___________. 1999b. Hawai'ian Wetland Refuge Habitat Management Review. United States Fish and Wildlife Service Refuges and Wildlife Region I, Portland, Oregon.

Vaa, S. J., K. L. Cool, and R. L. Linder. 1974. Nesting by American Coots in South Dakota. Proc. S.D. Academy Science 53:153-156.

Vogel, J. A. 1999. Migration chronology and habitat use of webless migratory game birds in the lower Missouri river floodplain wetlands. M.S. Thesis. University of Missouri-Columbia.

Walker, R. L., J. S. Medeiros, R. S. Saito, P. Sekora, G. Swedberg, T. Telfer, D. H. Woodisde, and F. Zeillemaker. 1977. Hawai'ian waterbird recovery plan. United States Fish and Wildlife Service, Portland, Oregon.

Weller, M. W. 1961. Breeding biology of the least bittern. Wilson Bulletin 73:11-35.

___________. 1999. Management of marshes for wildlife. Pages 267-284 *in* Freshwater Wetlands. Academic Press, Inc

___________, and L. H. Fredrickson. 1974. Avian ecology of a managed glacial marsh. Living Bird 12:269-291.

___________, and C. E. Spatcher. 1965. Role of habitat in the distribution and abundance of marsh birds. Iowa Agriculture Home Econ. Exp. Sta. Rep. No. 43.

Woodall, P. F. and D. F. Perry. 1982. Water loss during incubation of red bishop (*Euplectes orix*) eggs. South Africa Journal of Zoology 72(2):75-78.

Woodside, D. H. 1979. Description of waterbird habitats as related to food availability and feeding behavior of endangered waterbird species on the islands of Kaua'i and O'ahu. Progress Rep., Job no. R-III-D, Project no. W-18-R-4. Div. For. Wildl., Honolulu.

Ziebell, T. J. 1990. Nesting least bitterns on Rush Lake, Wisconsin. Passenger Pigeon 52(1):19-28.

Appendix 1

Nest site descriptions: List of variables

	Variable	Description
1.	Nest #	Nest number, individual number assigned to each nest
2.	Date	Date active nest discovered or revisited
3.	Nest Height	Height of nest above substrate (cm)
4.	Cup Depth	Depth of nest's interior below the outer rim (cm)
5.	Nest Diameter	Greatest exterior diameter of nest structure (cm)
6.	Nest Material	Predominant materials used in the nest construction
7.	Water Distance	Distance from center of nest to nearest body of water (cm)
8.	Water Depth	Height of outer nest rim above nearest water level (cm)
9.	Clutch	Clutch size
10.	Egg Weight	Egg weight (g)
11.	Egg Length	Egg length (cm)
12.	Egg Diameter	Egg diameter (cm)
13.	# Egg Hatched	Total Number of eggs hatched in nest
14.	Cover Type	Describes predominant nest cover closest to the nest
15.	Cover Distance	Distance from nests center to nearest cover (cm)
16.	Vegetation	Total Vegetation Height
17.	Vegetation Ave.	Average Vegetation Height at Nest

Appendix 2

Habitat: Habitat used by birds.

1. (DM) Dry Mud
2. (WM) Wet Mud
3. (MI) Mud/Water Interface
4. (OW) Open Water
5. (RV) Residual Vegetation (short vegetation, treated areas)
6. (RE) Robust Emergent Vegetation (live or dead thick *Batis* or CA grass, etc.)
7. (OE) Other Emergent Vegetation (perennials)
8. (AS) Artificial Structure (dikes, levees)

Location: Location used by birds.

1. Spot Scan Control (OT, IP, NP, SP)
2. Complete Roto-tilling Treatment (A, B, C, D)
3. Island Roto-tilling Treatment (A, B, C, D)
4. Treatment Control (A, B, C, D)

Behavior: Activity of birds.

1. (FE) Feeding
2. (LS) Loafing/Sleeping
3. (FL) Flushed
4. (LO) Locomotion
5. (FY) Flying
6. (OR) Other

Water Depth: Water depth at use site.

1. (DM) Dry Mud
2. (WM) Wet Mud
3. (MI) Mud/Water Interface
4. (FO) Foot
5. (FT) Foot to Tarsus
6. (JO) Joint
7. (JB) Joint to Body
8. (BO) Body
9. (SW) Swimming